THE ECONOMIC ANALYSIS OF GEOTHERMAL/ABSORPTION COOLING OF A HOSPITAL: CASE STUDY OF DOKUZ EYLÜL UNIVERSITY RESEARCH AND APPLICATION HOSPITAL

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ABSTRACT

Dokuz Eylül Research and Application Hospital, founded in 1982, is located in İnciraltı place, in Balçova. It is placed at the south of İzmir and between the İzmir-Çeşme Highway and İzmir-Çeşme Super Highway. Rather rich geothermal resources found in Balçova, provides the use of geothermal water for heating in the hospital. However, the required cooling capacity for the hospital, which is relatively massive when compared with the residents, has been supplied by conventional compression chillers.

In this study, the aim is to decrease the overall annual costs incurred by cooling of the hospital by implementing an absorption cooling system, which uses geothermal fluid as the heating source. The main idea behind this implementation is that the electricity consumption of an absorption chiller is minimal when compared with a compression chiller. On the other hand, since the source that is going to be used in the system is geothermal energy, there will be an additional cost incurred by the use of geothermal fluid. So, the economic analysis that is going to be conducted involves the comparison of two alternatives, which are leaving the system as is now and implementing an absorption cooling system.

To minimize the costs incurred by the implementation of an absorption cooling system, instead of supplying the full capacity of the hospital, a moderate capacity will be supplied by the absorption chillers, by using the existing compression chillers as the peaking units. Since it is not known which capacity will be suitable for the needs, several absorption cooling machines with various capacities will be examined.

After comparing these mutually exclusive alternatives, the effect of the change in geothermal fluid price on the implementation of an absorption cooling system, and the break-even geothermal water price will be found.

At the end, the investment worth values of the selected absorption cooling machines will be examined to decide whether to implement an absorption cooling system in the hospital or not.

ÖZET

1982 yılında kurulmuş olan Dokuz Eylül Tıp Fakültesi Hastanesi, Balçova'nın İnciraltı bölgesinde bulunmaktadır. İzmir ilinin güneyinde yer almakta olup, İzmir-Çeşme karayolu ile İzmir-Çeşme otoyolu arasındadır. Balçova bölgesinde bulunan zengin jeotermal kaynaklar, ısıtmada jeotermal su kullanılmasını sağlamıştır. Ancak, konutlara göre çok yüksek olan soğutma kapasitesi, konvensiyonel kompresörlü soğutma cihazlarıyla karşılanmaktadır.

Bu çalışmada amaç, hastaneye ısıtma kaynağı olarak jeotermal su kullanan bir absorpsiyonlu soğutma sistemi entegre ederek soğutma ile ortaya çıkan yıllık maliyetleri azaltmaktır. Bu sistemi entegre etmekteki ana fikir absorpsiyonlu soğutucuların elektrik sarfiyatının, kompresörlü sistemlerle karşılaştırıldığında çok az olmasıdır. Diğer yandan, sistemde kullanılacak olan ısı kaynağı jeotermal enerji olduğundan, jeotermal su kullanımından doğan ek bir maliyet oluşacaktır. Yani, yapılacak olan ekonomik analiz, sistemin şimdiki haliyle absorpsiyonlu bir soğutma sistemi entegre edilmiş halinin karşılaştırılması olacaktır.

Maliyetleri en düşük düzeyde tutabilmek amacıyla hastanede bütün yükü karşılayabilecek absorpsiyonlu bir soğutma sistemi kurmaktansa, ortalama yükleri karşılayacak ve pik yüklerde hastanedeki mevcut soğutma sistemini kullanacak bir soğutma sistemi düşünülmüştür. Bu noktada, hangi kapasitedeki absorpsiyonlu sistemlerin daha uygun olacağı bilinmediğinden, farklı kapasitede birkaç absorpsiyonlu makine incelemesi yapılacaktır.

Uygun alternatiflerin karşılaştırılmasından sonra, jeotermal akışkan fiyatının absorpsiyonlu soğutma sistemlerinin uygulanabilirliği üstündeki etkisi incelenecek ve seçilen absorpsiyonlu soğutma makinelerinin ekonomik olabilmesi için gerekli jeotermal akışkan fiyatları bulunacaktır.

Sonuçta, absorpsiyonlu bir soğutma sisteminin hastaneye uygun olup olmadığını belirlemek için, seçilen absorpsiyonlu sistemlerin yatırım değerleri incelenecektir.

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CHAPTER 1

INTRODUCTION

From the beginning of the 19th century, absorption cooling systems attracted increasing interest, since it is possible with these systems to recover energy by using waste heat and thermal solar energy for cooling applications. Absorption coolers have been mass-produced since the 1960s. Arkla Industries (today Robur Spa) has produced over 300 000 small coolers with outputs of 10,5 - 17 kW (Lazzarin et al. 1996). Current coolers cover a range from 10 to 5000 kW.

The main characteristic of absorption cooling systems is that they produce cooling by using heat energy as an input, rather than by using mechanical energy. For this reason, absorption chillers were common in facilities that had large boiler plants with excess capacity during the cooling season. Unfortunately, absorption cooling is inefficient, and therefore absorption chillers are appeared to be replaced by compression chillers. However, new circumstances, like increasing amount of waste heat and the desire to recover this waste, are giving absorption chillers a revival.

When the absorption chillers are examined from constructional points of view, the components of them should be integrated much more closely than the components of a compression cooling system. As a result, all absorption chillers are contained within a single compact package. For the same reason, absorption chillers have few variations. In all large absorption systems, cooling is distributed by chilled water. Similarly, all condensers are cooled by water, usually from a cooling tower (Wulfinghoff 2003).

The main differences between the models are in the heat source and in the number of stages. Originally, the energy source for absorption chillers was steam or high-temperature hot water. Nowadays, direct-fired systems using an integral boiler are gaining popularity because of its greater efficiency. Older absorption machines were single-stage machines. However, they are being replaced by two-stage machines, which provide substantially higher efficiency. Virtually all direct-fired absorption machines are two-stage.

The most commonly used pairs of working fluids are ammonia-water and water-LiBr. For ammonia-water systems, ammonia is the refrigerant and the water is solvent, while for water-LiBr systems water is the refrigerant and LiBr is the solvent. Temperature ranges of the machines are determined by the thermodynamic properties of the refrigerant. The boiling temperature of the ammonia at 10^5 Pa is -33°C, which enables the machines with ammonia-water pairs to be used for freezing. However, refrigerant water is only available at temperatures above 0°C, which makes it possible to use for cooling and air-conditioning (Herold et al. 1996, Srikhirin et al. 2001).

In LiBr systems, the extremely low refrigerant pressure, which is around 10^3 Pa at 5°C is favorable for small pump power and uncomplicated constructions. Another advantage of the LiBr systems is the high boiling point distance between the refrigerant and the solvent, which creates a pure refrigerant vapor when the refrigerant is expelled from the solution. In ammonia-water systems, the boiling point distance is only around 133 K, which results in boiling of some water (solvent). This solvent should be removed from the refrigerant vapor in a rectifying column.

The main drawback of the LiBr systems is the possibility of the solvent to be crystallized. If during the expulsion of the refrigerant, the refrigerant concentration in the solution drops too sharply, it can cause the remained solvent to be crystallized. This leads to a malfunction of the machine (Eicker 2003).

The main energy source that is going to be used for absorption cooling systems in this study is geothermal energy. Geothermal energy is literally the heat contained within the Earth that generates geological phenomena on a planetary scale. However, the term geothermal energy is often used to indicate the Earth's heat that can be recovered and exploited (Mathur et al. 1983).

Direct use of geothermal energy refers to the immediate use of geothermal energy rather than converting it to some other form such as electricity. The main application areas for direct use applications are swimming, bathing, balneology, space heating and cooling, greenhouse heating, fish farm heating, raceway heating, industrial processes and heat pumps. An estimate of the installed thermal power for direct-use applications at the end of year 2004, is 27.825 MW. The thermal energy used by category is 33% for geothermal heat pumps, 29% for bathing and swimming, 20% for space heating, 7.5% for greenhouse and open ground heating, 4% for industrial process heat, 4% for aquaculture pond, less than 1% for agricultural drying, less than 1% for snow melting and space cooling and less than 0.5% for other uses. Space cooling is limited, amounting to 288,5 TJ/yr and an installed capacity of 55,6 MW.

In Turkey, of the 170 prospects that have been identified, 95% are in low-to-medium enthalpy range, which is mostly suitable for direct-use applications (Şimşek et al. 2005). The installed capacity is now 1.177 MW and total use is 19.623 TJ/yr with a capacity factor of 0,53. Direct use applications consist of mainly district heating where 65.000 residences are being heated now with a capacity of 645 MW and use of 6.015,4 TJ/yr. Individual space heating applications has a capacity of 74 MW and use of 816,8 TJ/yr. For greenhouse heating, with a total area of 635.000 m^2, total capacity is 131 MW and total use is 2.478,7 TJ/yr. Bathing and swimming applications also constitute a major part of the total direct use applications, with a capacity of 327 MW and use of 10.312,2 TJ/yr.

There are 54 sites in Turkey, which have a combined space heating and spa use of geothermal energy, and 195 balneological facilities that use geothermal heat. The proven potential is calculated at 3.293 MW, while the estimated geothermal potential is at 31.500 MW, a figure which indicates that 30% of the total residences in Turkey could be heated by geothermal energy (Lund et al. 2005).

Most direct use applications require a geothermal source from a low to medium temperature range about 50^{o}C to 150^{o}C. Low-temperature systems can be more widely found with respect to high temperature systems (Cataldi et al. 1999).

The Lindal Diagram, which is named after Baldur Lindal, the Icelandic engineer who first proposed it, defines the temperature ranges suitable for various direct use activities (WEB_1 2005). When this diagram is examined, it can be seen that cooling and industrial applications normally require a temperature above 100^{o}C.

The case study chosen for this study is Dokuz Eylül University Research and Application Hospital. It is located in Balçova, and is placed at the south of İzmir and between the İzmir-Çeşme Highway and İzmir-Çeşme Super Highway.

The planning studies for Dokuz Eylül University Research and Application Hospital were started and included in a five year plan beginning from 1983. Hospital's total area is 105 acres, total use area is 103.000 m^2 and the total bed capacity is 2044. Currently, the hospital composed of 14 buildings. Out of these 14 buildings, ten of them are cooled by the compression chillers found in the hospital (WEB_2 2005).

The hospital is heated by geothermal energy, which is also planned to be used for cooling. This energy is supplied by İzmir Geothermal Inc., which is located in

Balçova region and has 13 active production wells. The total capacity of these wells is 1350 m^3/h and the weighted average temperature is 115°C. At the peak heating load of the İzmir Geothermal District Heating System, the geothermal fluid consumption is 765 m^3/h. So, even at the peak load of the system, there is an available capacity of 585 m^3/h geothermal fluid at 115°C. The design temperature range taken throughout this study will be 110-120°C. Although the average temperature is 115°C, it is possible to supply geothermal fluid to the hospital at 120°C (Aksoy 2003).

The wells that are being used for heating DERAH are BD8 and BD10, which are part of Balçova-Narlıdere Geothermal District Heating System. Layout of Balçova-Narlıdere Geothermal District Heating System has been given in Figure 1.1.

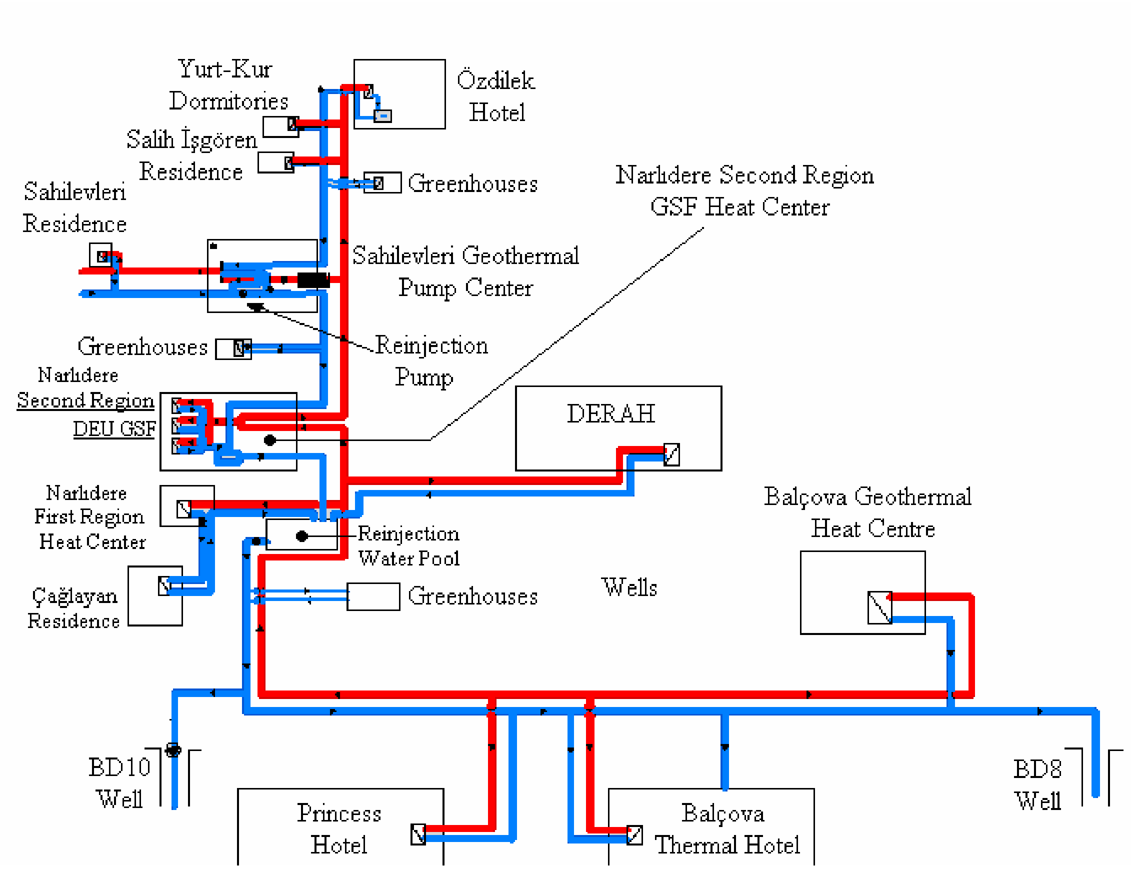


Figure 1.1. Layout of Balçova-Narlıdere Geothermal District Heating System

The average geothermal fluid temperature that enters the hospital is around 125°C. The heating system of the hospital works between 110°C and 60°C. For heating purposes, hospital's annual average geothermal fluid use is around 40 m^3/h. When the heating season is considered which composes of six months starting from november, the average use becomes 80 m^3/h. Throughout the heating season, the geothermal fluid use reaches its maximum at 110 m^3/h (Küçüka, Gökdaş 2003).

During this study, in Chapter 2, the absorption cooling systems and their working principle will be explained.

In Chapter 3, the economical terms that will be used in the study will be explained and an overview about making an economic analysis will be given.

In Chapter 4, the existing cooling system of the hospital will be examined and its annual electricity consumption and annual cost will be found.

In Chapter 5, selected absorption cooling machines, which have capacities of 4,818 MW, 2,288 MW and 1,496 MW, are examined and their annual geothermal water consumption and annual costs have been found.

In Chapter 6, the results found as a result of the calculations done on the absorption cooling systems are given. And finally, in Chapter 7 the results are concluded and some recommendations are made.

CHAPTER 2

ABSORPTION COOLING SYSTEMS

Absorption cooling systems provide cooling through an evaporation/ condensation process. The main differences between conventional compression cooling systems and the absorption cooling systems are that absorption chillers usually use water rather than a standard refrigerant, they operate at lower pressure conditions rather than at moderate or high pressures, and they use heat rather than a compressor as a driving force (Hondeman 2000).

Direct comparison between these systems shows that condenser, throttling valve and the evaporator, which are found in compressor systems, are basically the same in the absorption coolers. The difference is that instead of a compressor, there are some additional components. These are the generator, solution heat exchanger, solution pump, throttling valve and the absorber. Component comparison between these systems has been shown in Figure 2.1.

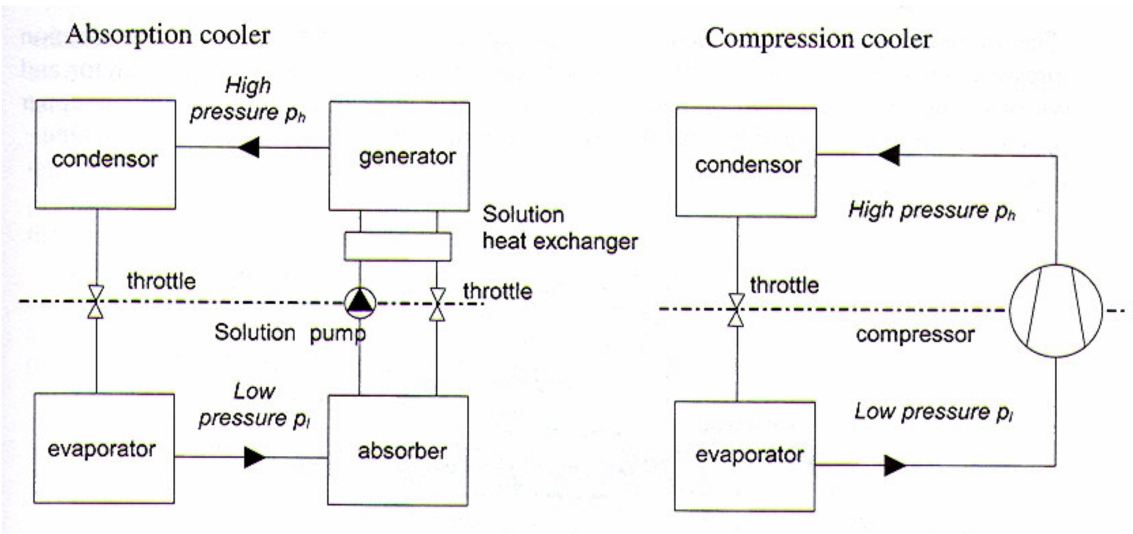


Figure 2.1. Components of the absorption cooler compared with a compression cooler.
(Source: Eicker 2003)

Absorption cooling systems have certain advantages among the conventional vapor compression systems. Absorption systems use pumps instead of the compressors that are used in vapor compression systems. Since pumping a liquid to high pressures requires much less electricity than compressing a gas to the same pressure, electricity consumption is less than a vapor compression cycle. Also the refrigerant is usually water that has no damaging effect on ozone layer when compared with the chlorofluorocarbon (CFC) refrigerants used in vapor compression cycles (Hondeman 2000).

During the operation, absorption cooling systems generates less noise, works on relatively low pressures and it is safer to maintain the operation with these systems. There is no large rotating component, which leads to a smaller space requirement compared to an electric chiller. The reliability of the absorption cooling systems is high, and the maintenance costs are relatively low (Eicker 2003, Hondeman 2000).

The absorption cooling systems use the high affinity between two substances. Usually the one that evaporates at a lower temperature called refrigerant while the other is called absorbent. The principle is that the system uses an absorbent liquid to attract and pull a refrigerant from the evaporator. The high affinity of the refrigerant for the absorbent causes the refrigerant to boil at a lower temperature and pressure than it normally would and transfers heat from one place to another. At the beginning of this attraction process, the concentration of the refrigerant is low so that solution has a strong attractive force on refrigerant. At this state, it is difficult to separate the refrigerant from absorbent and the solution is named to be a strong solution. While the concentration increases, the attractive forces decrease. It becomes easier to separate the refrigerant and the solution becomes a weak solution. At this state, heat is added to separate the refrigerant from the absorbent, send it to the evaporator and the cycle repeats (Lazzarin et al. 1996, Herold et al. 1996, Srikhirin et al. 2001, Odabaşı 2001).

Commonly used pairs of working materials are ammonia-water and water-LiBr with ammonia and water as refrigerants and water and LiBr as solvents. The main characteristic property of the refrigerant is that its phase changes easily between liquid and vapor. Also it is the fluid that circulates in the system, so that refrigerant should be chosen with the materials and conditions it will be used to prevent corrosion and maintain reliability. While choosing the absorbent, the main aim is that it shows a high affinity with the refrigerant. Mostly the absorbents are chosen to be lithium bromide or ammonia (Herold et al. 1996, Srikhirin et al. 2001).

The possible temperature range of the absorption machines are determined by the thermodynamic properties of the refrigerants. For example, at a pressure of 10^5 kPa ammonia boils at -33°C and therefore can be used for cooling and air conditioning. However, the refrigerant water has evaporation temperatures above 0°C and used for pure air conditioning.

One advantage of LiBr systems is that the refrigerant pressure is extremely low like 10^3 kPa at 5°C and it is favorable due to the small pump power and simple construction. Another advantage is the high boiling point distance between the refrigerant and the solvent. As a result of this, when the refrigerant is expelled from the solution, pure refrigerant vapor develops. On the other hand, the boiling point distance between water and ammonia is 133 K. So, when the refrigerant is expelled from the solution, water vapor, as well as the ammonia vapor, is produced and therefore should be separated in a rectifying column. Although these advantages, the major disadvantage of the LiBr systems is that it is possible for LiBr to crystallize when the refrigerant concentration in the solution drops too sharply (Eicker 2003).

2.1. Classification of Absorption Cooling Systems

Absorption cooling systems are divided into two categories according to the heat source they use. Direct-fired systems contain a burner that runs on natural gas or another fuel to produce the heat required for the absorption process. Indirect-fired systems use steam or hot water, produced externally by a boiler or cogeneration system. A system of piping and heat exchanger transfers the heat to the system. Also these systems could be classified as water-cooled absorption systems and air-cooled absorption systems. Water-cooled absorption systems that are available on the market usually use water as a refrigerant and a lithium bromide solution as the absorbent, while the air-cooled absorption systems usually use ammonia as the refrigerant and water as the absorbent (Herold et al. 1996, Srikhirin et al. 2001, Eicker 2003).

Another classification for these systems could be made according to the number of refrigeration cycles used in the system. Single-effect cooling systems use thermal energy to drive a single refrigeration cycle. Single-effect systems are usually suitable for lower temperature applications, probably around 75-132°C. Double-effect cooling systems use two refrigeration cycles. The first is driven by high temperature thermal energy and the second is driven by lower temperature energy rejected by the previous cycle's condenser. The double-effect systems require steam at around 190°C and 900 kPa. The comparison for the coefficient of performance figures for multistage absorption chillers are given in Figure 2.2 (Grossman 2002).

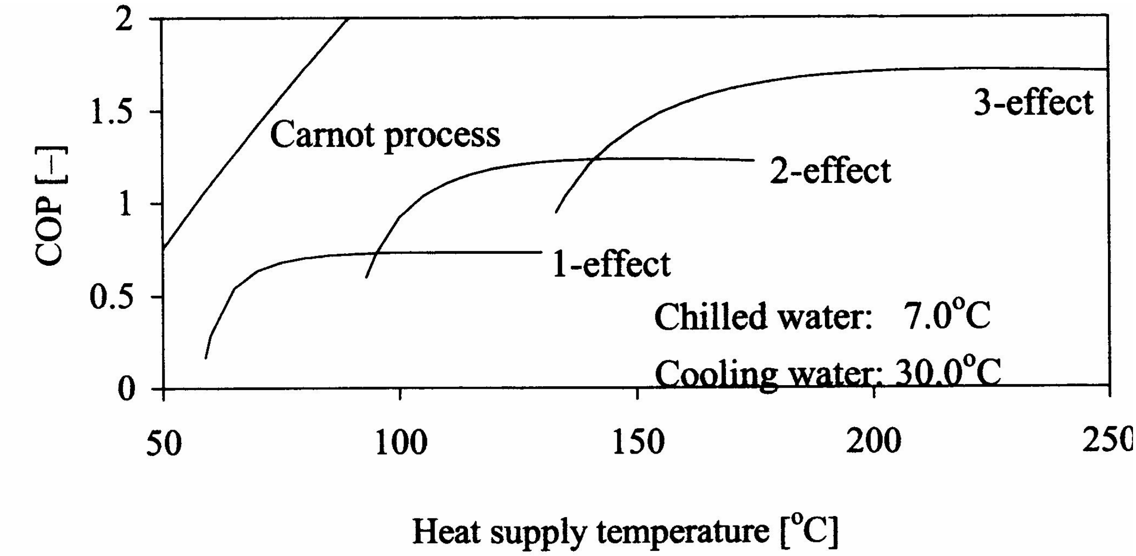


Figure 2.2. Comparison of COPs for multistage absorption chillers.
(Source: Grossman 2002)

Today, in the market, the absorption cooling systems range in capacity from less than 10 kW up to over 6000 kW(3 tons to 1700 tons). For the single-effect absorption chillers, coefficient of performance values are around 0,7, while for double-effect absorption chillers it could be as high as 1,3. Although these values are seemed to be low compared to the vapor compression chillers, the low electricity consumptions could make the double-effect absorption chillers more economical, which are usually direct-fired systems that use natural gas as a fuel. For single-effect systems, the COP values are very low. However, the heat source that is used for generator is usually waste heat from a facility or geothermal energy. Since the cost of heat is not a consideration for waste heat and very low for geothermal energy, indirect-fired systems could still be economical compared to the vapor compression systems.

For the case study, since the geothermal fluid temperature is around 110-120°C, it is possible to implement a single-effect absorption chiller. In this case, the COP of the machine will be around 0,7.

2.2. Working Principle of Absorption Cooling Systems

The basic operating principle of an absorption chiller is the same as that of a conventional vapor compression chiller. Instead of the compressor in the vapor compression chiller, there are absorber, pump and generator. Arrangement of a simple absorption cooling cycle is given in Figure 2.3. Heat is given to the generator, which contains a weak solution of an absorber and a refrigerant. The refrigerant evaporates, since the attractive forces are low for a weak solution. This water vapor comes to the condenser. Here it gains heat from the place that is going to be cooled and condensed. After condensation, it is throttled through the evaporator, and lose its heat to the surrounding. After that, it turns to the absorber, which contains a strong solution of the absorber and the refrigerant. The attractive force of the absorbent helps the refrigerant to condense at a lower pressure and temperature than it normally would. After condensation, the solution becomes a strong solution and it is pumped to the generator, so that the cycle continues (Lazzarin et al. 1996, Herold et al. 1996, Srikhirin et al. 2001, Eicker 2003, Hondeman 2003).

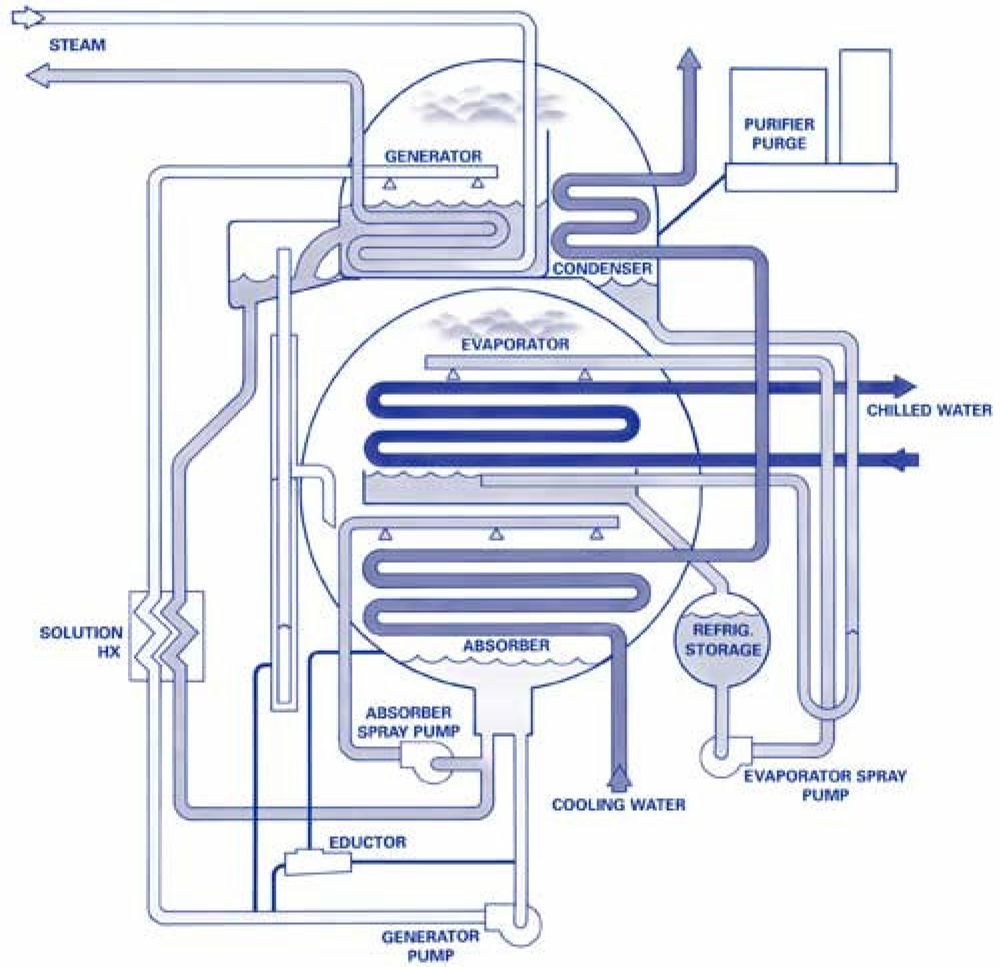


Figure 2.3. Arrangement of the components of an absorption cooler on a LiBr water basis.

(Source: WEB_3 2005)

CHAPTER 3

ECONOMIC ANALYSIS OF A PROJECT : AN OVERVIEW

The aim of the economic analysis of projects is to maintain a better allocation of resources, which leads to enhanced incomes for investment. For a directly productive project, for which the output is sold in a competitive environment, the selected projects meet a minimum standard for resource generation and the choices should have to be made to eliminate the projects that do not meet the standards. However, for indirectly productive project, where the ouput is not sold, choices are made for the project by different means of achieving the same objective. For this kind of projects, it is possible to find the best alternative by choosing the project, which needs the lowest resources for a given output (WEB_4 2005).

There are four basic steps in analyzing the economic feasibility of a project:

1. Identifying the economic costs and benefits
2. Quantifying the costs and benefits
3. Determining the values of the costs and benefits
4. Comparing the benefits with the costs

The first two steps can be examined together. However, there can be some types of costs and benefits that cannot be quantified and valued in the economic analysis. They can be stated alongside the economic analysis. One example of this kind of benefits can be the descending amounts of pollution emission in an area due to an implemantation of a renewable energy project (WEB_4 2005).

To determine the project costs and benefits, the situation without the project should be compared with the situation with the project. This comparison is necessary to estimate the net benefits of the project. The without-project situation is often inaccurately described. In most cases, it is a modification of the existing circumstances. However, in comparing project alternatives, the without-project situation provides the basis for comparing with-project's net benefit flows for each alternative (Park 2001).

Most projects doesn't have effects on the prices of the project inputs and outputs, and obviously won't have any impact on government budget. However, in the case of large projects, which have considerable effects on the regional, national or international economy, additional factors should have to be taken into account (WEB_4 2005).

Another important distinction in identfying the project benefits and costs is that between the nonincremental and incremental outputs, since they are valued in different ways. When the project outputs have been substituted for existing production, the outputs are nonincremental. For example, a hydropower plant may be a substitute for an existing coal-fired power plant. However, when the project outputs have been increased by increasing supplies to meet the demand, the outputs became incremental. For example, the growing demand for electricity can lead to the decision to construct a new power plant without retiring any existing power plants. Each project will experience different amounts of incremental and nonincremental effects for outputs. So, it is necessary to analyze these effects for the main project output (Park 2001, Sepulveda et al. 1984).

3.1. Identification and Quantification of Benefits

For directly productive projects, the main benefits will be the net income gained from the production that is sold. While forecasting this income, it is first necessary to determine whether the project is incremental or not. If the project size is small with respect to the market size, it is usually the case that the project is fully incremental. Otherwise, the project can cause price effects where nonincremental output displaces sales from higher-cost manufacturer (Park 2001, Sepulveda et al. 1984, Castillo 1998).

For indirectly productive projects, the need for services depend on the underlying factors such as the rate of electricity consumption. The key feature for these projects is to make an investment to meet the demand. In much of the indirectly productive projects, the project benefits can be quantified as time and cost savings, improved health, and so on (Park 2001, Sepulveda et al. 1984, Castillo 1998).

Some benefits of the indirectly productive projects cannot be quantified. For example, making a new bridge will not only reduce travel time but may also encourage greater social and political interaction between the two sides of the river. Another example can be a dam project, which creates a reservoir that not only used for fishing but also offered a recreational area for the inhabitants (Park 2001, Sepulveda et al. 1984, Castillo 1998).

3.2. Identification and Quantification of Costs

Several types of costs need to be included in the economic analysis of a project. While quantifying these costs, the project that are going to be quantified are found by calculating the difference in costs between the without and with project situations, that is, the extra use of resources necessary to achieve the corresponding benefits. The type of costs that can be incurred during a project are explained seperately below (WEB_4 2005, Castillo 1998).

3.2.1. System Costs

If a project is a part of a larger project and incremental, it cannot be applied unless matching investments at the whole system has been made. For example, when increasing the power generation capacity, it is also necessary to make some investments on the existing transmission and distribution systems. The project should include the costs of the whole system required to achieve the benefits. If the total system of projects is viable, then the project is also viable (WEB_4 2005).

3.2.2. Sunk Costs

A project may require to use existing facilities that are already in use. The costs for such facilities are sunk costs and should not be included in the project cost, since their use in the project involves no oppurtunity cost (Park 2001, Sepulveda et al. 1984).

3.2.3. Working Capital

Working capital is also interpreted as the net current assets, which consists of inventories, net receivables, bank balances and cash in hand. For purposes of economic analysis, only inventories should be included in the project economic costs (WEB_4 2005).

3.2.4. Depreciation

The financial accounting will include the provision for depreciation and amortization costs as a seperate cost. However, for economic analysis of a project, the investment necessary to create a certain amount of benefit includes the initial investment and replacements during the project life (Park 2001).

3.2.5. External Costs

The effect of a project can go beyond the financial analysis point of view. These external costs may include costs that must be accounted for an economic analysis from the national perspective (WEB_4 2005).

3.3. Least-Cost Analysis and Choosing Between Alternatives

The aim of the least-cost analysis is to identify the least-cost project option for supplying output to meet the forecasted demand. Among the mutually exclusive projects, selection of least-cost option promotes the production efficiency. However, least-cost analysis cannot provide an indication of the economic feasibility of the project, since the costs incurred by the project may exceed its benefits. So, at the end of least-cost analysis, a benefit-cost analysis should have been made to find whether the net present or future value of the project is positive (WEB_4 2005, Park 2001, Sepulveda et al. 1984).

Least-cost analysis enables ranking the mutually exclusive projects, which produces the same amount of output at the same quality. Since the benefits are the same, it becomes necessary to compare only the costs incurred by the projects and select the alternative with the least present or future value (WEB_4 2005).

Since, the capital invested to a project can earn an interest itself, this interest is the oppurtinity cost that is wasted. So, while calculating the present or future value of the project, the oppurtinity cost of the capital should be substracted from the benefits (WEB_4 2005).

Alternative options may consist of different design, technologies, and sizes. Also they can be the same project with an alternative location. However, being mutually exclusive, these projects should be realistic, so that selection of one alternative totally rejects the others. In case the output of the alternatives does not hold each other, a normalization should be applied to the results or the difference in the output should be supplied with other alternatives, which in case will be added to those alternative as costs (Park 2001, Sepulveda et al. 1984).

Least-cost analysis can be applied to the projects when it is possible to quantify and value the effects and outcomes. In some cases, where the project effects can be quantified but not valued adequately, project selection can be made based on the results of the cost-effectiveness analysis. The purpose of cost-effectiveness analysis is to minimize the resource use to produce the same amount of output, or in the case of scarce resources, to maximize the output for a constant input. In cost-effectiveness analysis, the effects of the projects needs not to be expressed in terms of monetary value. It can be applied to any project as soon as the effects are quantifiable (WEB_4 2005).

Alternatively, if the outcome of a project is homogeneus product with the same quantity and the quality, the average incremental cost can be established. It can be found by dividing the present worth of the incremental investment and annual costs to the present worth of the incremental output. The aim of finding the average incremental cost is to determine the project with less costs per unit production (WEB_4 2005).

3.4. Time Value of Money

Time value of the money suggests that money available at the present time worth more than the same amount in the future, due to its potential to earn money. Provided money can earn money, which yields the result that the same amount of money worth more the sooner it is received (WEB_5 2005).

To understand the time value of money clearly it is first necessary to understand the interest and the interest rate concepts. The return derived from an investment is interest, and the fraction by which the return of the investment calculated is called the interest rate (WEB_6 2005). To find the interest of a project, interest rate is applied to the present worth of the investment. When this interest is added to the present worth, the future worth of the investment can be found. Future worth can also be found by adding 1 to the interest rate and directly multiplying that value with the present worth of the investment. The formula to find the future worth of an investment is given below.

$$FV = PV \times (1 + i) \tag{3.1}$$

Where,

FV = Future value of the investment

PV = Present Value of the investment

i = Interest rate

CHAPTER 4

EXISTING COOLING SYSTEM OF DOKUZ EYLÜL UNIVERSITY RESEARCH AND APPLICATION HOSPITAL (DERAH)

The existing cooling systems in the Dokuz Eylül University Research and Application Hospital (DERAH) consists of split and window type air-conditioners, roof-top system and compression chiller groups. The total capacity of split and window type air-conditioners is 1,24 MW and the total capacity of the roof-top system is 1,6 MW. Apart from the split type air-conditioners and the roof top system, the cooling system of DERAH mainly consists of the compression chiller groups. There are total number of 12 chiller groups in the hospital. Nine of them are Dunham-Bush WCFX42 branded water cooled screw type chillers. They each have capacities of 1,45 MW. Two of them are Gönka branded air cooled screw type chillers with capacities of 1,4 MW and one of them is Bluebox branded water cooled screw type chiller with a capacity of 0,95 MW. The total capacity of these chiller groups is 16,8 MW.

The general layout of the hospital with the locations of the chiller groups are given in Figure 4.1. Also in Table 4.1, the contents of the buildings has been given.

As can be seen from the figure, the nine of the Dunham-Bush chillers are located in two groups. Also, in third block they are seperated in two groups. Each group has three chillers. The first group is located in eleventh block. This group supplies the cooling load of seventh, eighth and the eleventh block. These three blocks contain the polyclinics of the hospital. The other two groups are located in third block. They are used in third, fourth and fifth blocks. The reason they are seperated as two groups is that one group is responsible for cooling the bed services while the other one is responsible for cooling the operating rooms. Dunham-Bush chiller groups are used throughout the whole year. Gönka air-cooled groups are located in second block. They are responsible for cooling first and second blocks. Gönka groups are usually used during cooling period. Bluebox water-cooled chiller is located in third building and responsible for cooling of the same building. Like Gönka groups, it is usually used during cooling period.

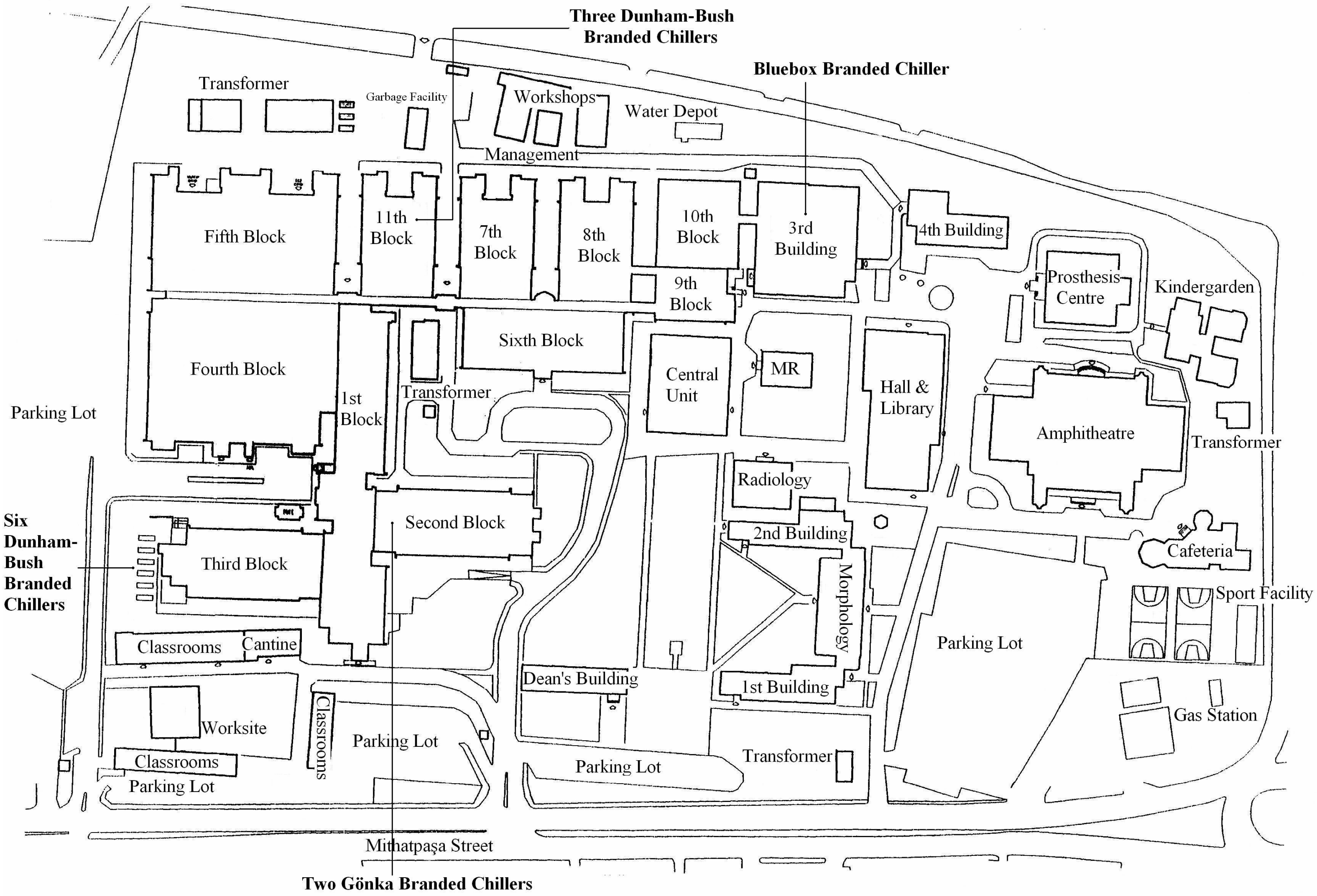


Figure 4.1. General layout of the DERAH and the ocations of the chiller groups.

Table 4.1. Building contents of each building

Compression Groups		2 Gönka	6 Dunham - Bush								3 Dunham - Bush			1 Bluebox
	1st Block (Beds)	2nd Block (Beds)	3rd Block (Beds)	4th Block	5th Block	6th Block	7th Block	8th Block	9th Block	10th Block	11th Block Polyclinic	1st Building Laboratories	2nd Building Laboratories	3rd Build. Oncology
2nd Basement				Depots Printery	Laundry Installment				Radiation Oncology		Depots			
1st Basement	Morgue Boiler Room Oxygen Vacuum	Installment Phone Central Data Procecssing	Installment	Emergency Day Hospital	Kitchen Pharmacy	Archive Polyclinic Entrance	Physical Therapy	Oncology Labs Hematology	Worker's Health	Radiation Oncology	Child Psychiatry Psychiatry	Microbiology	Histology	Infection
Ground	Patology	Surgeon General Working Capital	Blood Bank Internal Medicine	Central Lab Delivery Room	Radiology	Infection Data Processing Polyclinic Man.	Chest Disease	Urology	Nuclear Medicine	Nuclear Medicine	Oculogy	Biochemistry	Anatomy	Psychiatry
1st Floor	Internal Medicine Intensive Care Medical Supplies	Orthopedy	Pregnancy	Surgeries	Dialysis		Internal Medicine	Neurology Plastic Surgery			Dermatology Child Surgery	Medical Biology	Pharmacology	Biophysics Child Oncology
2nd Floor	Cardiology	Urology	Child Affection	Surgeries	Dining Hall		Child Affection	Delivery Room				Forensic Medicine	Physiology	Child Oncology
3rd Floor	Oculogy	Plastic Surgery	Child Surgery				Allergy Labs Anesthesia	Surgery			Cardiology			Cardiology
4th Floor	Physical Therapy	Surgery	Neurology Child Psychiatry											
5th Floor	Internal Medicine	Internal Medicine Infection	Chest Surgery Dermatology											
6th Floor	Psychiatry	Sleep Lab	Special Floor											

Since the Dunham-Bush branded compression chiller groups found in the hospital supply most of the cooling capacity of the hospital, and used throughout the year, only those groups are taken into consideration in this study, which have a total capacity of 13,05 MW. The other reason to consider them is that they are located as groups of three with available space, and it is possible to change those systems with absorption cooling systems.

In this chapter, first the monthly electricity consumption of the hospital will be given. Then, the monthly electricity use for cooling will be extracted out of this information. Based on the data, the cooling capacity curve will be drawn after making necessary assumptions. Finally, the annual operating cost of the existing compression chillers will be found.

4.1. Determining the Monthly Electricity Consumption

To determine whether implementing an absorption cooling system into DERAH is feasible or not, first it is necessary to find the monthly electricity use for cooling, instead of finding the annual electricity use, since the cooling load would differ considerably for every month. However, there is no available data about the actual electricity consumption of the chillers. For this aim, a procedure has been used to aproximate the annual consumption.

In this procedure, monthly total electricity consumption of the hospital has been obtained. To approximate an average value for the total electricity consumption of the hospital, the electricity bills between years 2000 to 2004 have been used. At this point, it is decided to determine the average electricity consumption values, which are going to be used in the calculations, with two different methods.

In the first method, the monthly electricity consumption values are approximated by taking the average of the 4 years for every month. The main advantage of this method is that it gives the desired parameters easily. However, it does not take the possibility for an increasing or a decreasing trend in the electricity consumption for the hospital into account.

Although, the graphs show fluctuations instead of a regular trend, a second method, which consists of applying linear regression analysis and forecasting electricity consumption values for the year of 2005, is also used. While using this method, it is seen that the R-square values are usually so low that the obtained values are not in a good agreement with the electricity consumption. Using another regression methods such as polynomial regression could give better results. The reason to use linear regression instead of using a polynomial regression is that the consumption values should be around the actual consumption values and although the polynomials give better R-square values, they usually give excessive results for the upcoming years. After obtaining the consumption values for the year 2005 with linear regression, these values are assumed to be constant for the rest of the project life. The graphics found by both methods can be seen in Figure 4.2 and Figure 4.3.

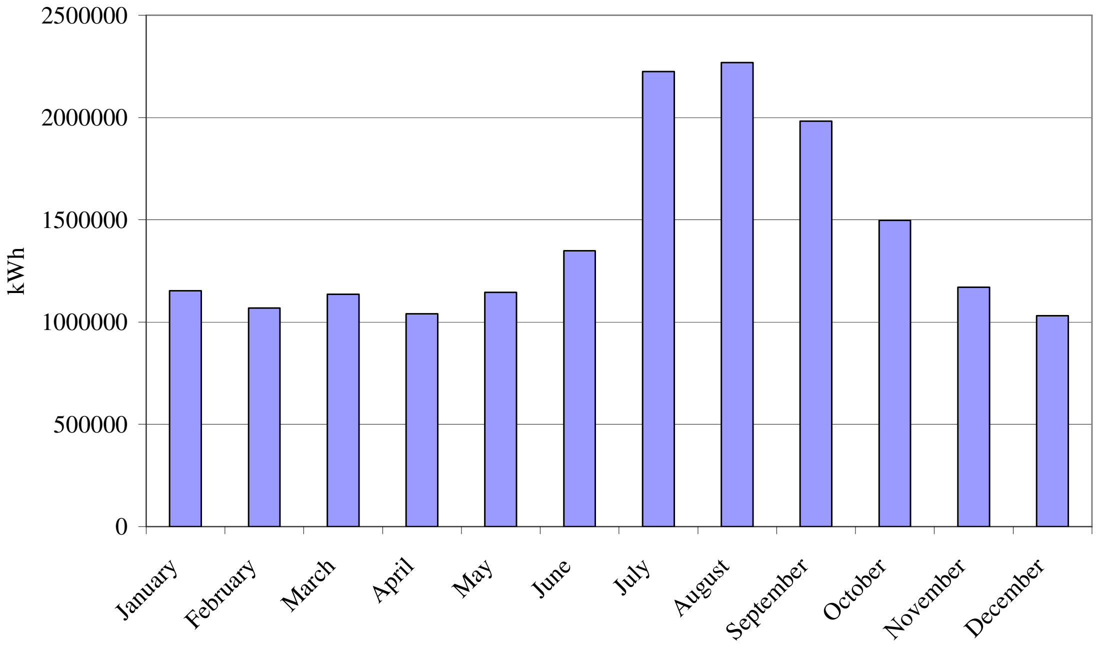


Figure 4.2. Total electricity consumption obtained by averaging (2000-2004)

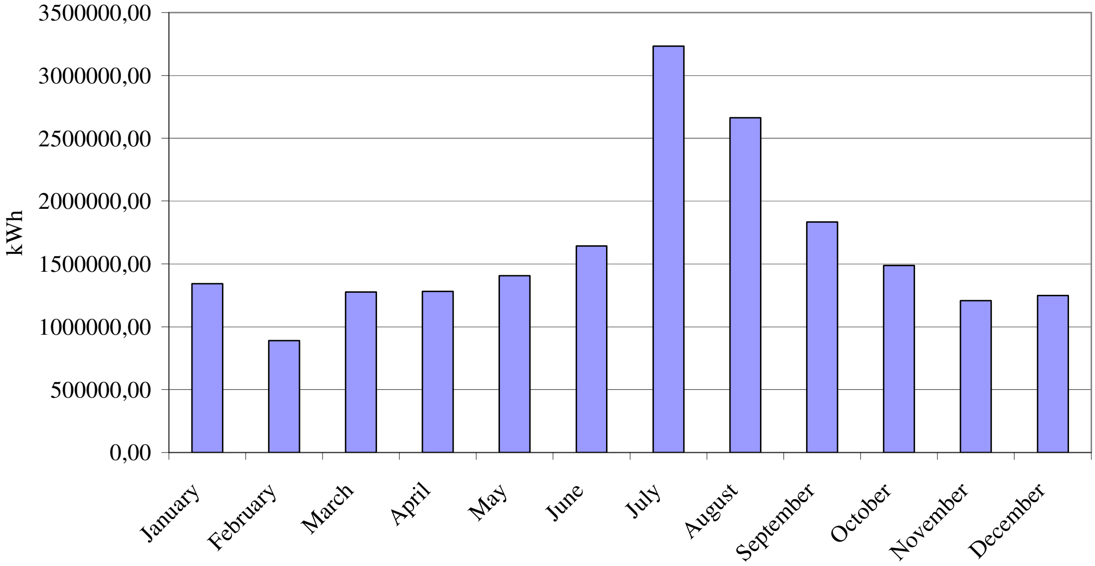


Figure 4.3. Total electricity consumption obtained by regression for year 2005

The values obtained by both methods for annual electricity consumption rates, are compared in Table 4.2.

Table 4.2. Monthly electricity consumption values

	Average (2000-2004) Values(kWh)	Forecasted Value for 2005 (kWh)
January	1.153.110	1.341.407
February	1.069.294	887.859
March	1.135.546	1.275.591
April	1.039.658	1.281.788
May	1.144.815	1.405.646
June	1.347.619	1.642.994
July	2.225.318	3.231.973
August	2.269.391	2.661.771
September	1.982.321	1.833.888
October	1.496.880	1.486.113
November	1.170.400	1.207.341
December	1.030.575	1.247.505
Total	**17.064.926**	**19.503.874**

In both methods, it is assumed that the electricity consumption would remain the same for the whole project life. Although it doesn't represent the actual case, this assumption still holds, since increased electricity consumption would be due to the new buildings that are going to be built and these buildings would probably be cooled by new chiller groups. Although in the case that it is made possible to supply some part of the new building's cooling load, this would also be in favor of the absorption cooling system, if the operation costs of the absorption system is lower. After all, if the operation costs of the absorption cooling system exceeds the compression cooling system, than it is not possible to implement an absorption system.

4.2. Determining the Electricity Consumption for Cooling

The main difference of a hospital from a resident is that it has a cooling load for the whole year. Therefore, the minimum load should have to be known to determine the electricity consumption for cooling. However there is no data about the minimum consumption of the chillers during a year. For this aim, an average amount of the cooling capacity that is being used for the month, which has the minimum cooling load, is obtained from the technical manager of the DERAH, which is 2,2 MW. At this point, it is necessary to make an assumption about the correlation between the maximum capacity and the maximum electricity consumption for cooling. Here, it is assumed that the system works at full capacity only on the month that the maximum load occurs. Also to relate the minimum capacity with the minimum electricity consumption for cooling, it is assumed that the consumption for cooling is directly proportional to the capacity used.

The maximum capacity is equal to:

$$Y = A - B + X \tag{4.1}$$

Where,

A = Maximum electricity consumption

B = Minimum electricity consumption

Y = Maximum electricity consumption for cooling

X = Minimum electricity consumption for cooling

Since it has assumed that the capacity is directly related with the consumption for all cases, it follows that:

$$X = \frac{K}{L} \times Y \tag{4.2}$$

Where,

K = Minimum capacity used for cooling
L = Maximum capacity used for cooling

If equation 1 is substituted into equation 2:

$$X = \frac{K}{L} \times (A - B + X) \tag{4.3}$$

If, the minimum electricity consumption for cooling has to be found, then:

$$X = \frac{K \times (A - B)}{L \times (1 - \frac{K}{L})} \tag{4.4}$$

After finding the minimum electricity consumption used for cooling, it is possible to find electricity consumption for cooling for each month:

$$N = M - B + X \tag{4.5}$$

Where,

N = Electricity consumption for cooling for n^{th} month
M = Electricity consumption for n^{th} month

Monthly electricity consumption for cooling found by both methods can be seen in Figure 4.4 and Figure 4.5.

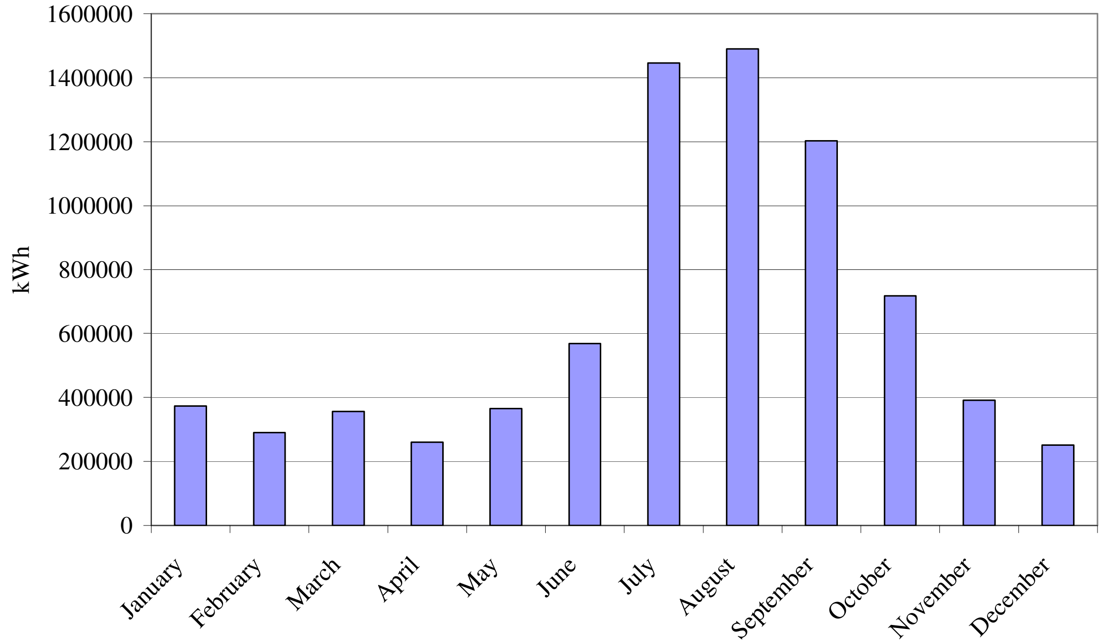


Figure 4.4. Total electricity consumption used for cooling found by averaging

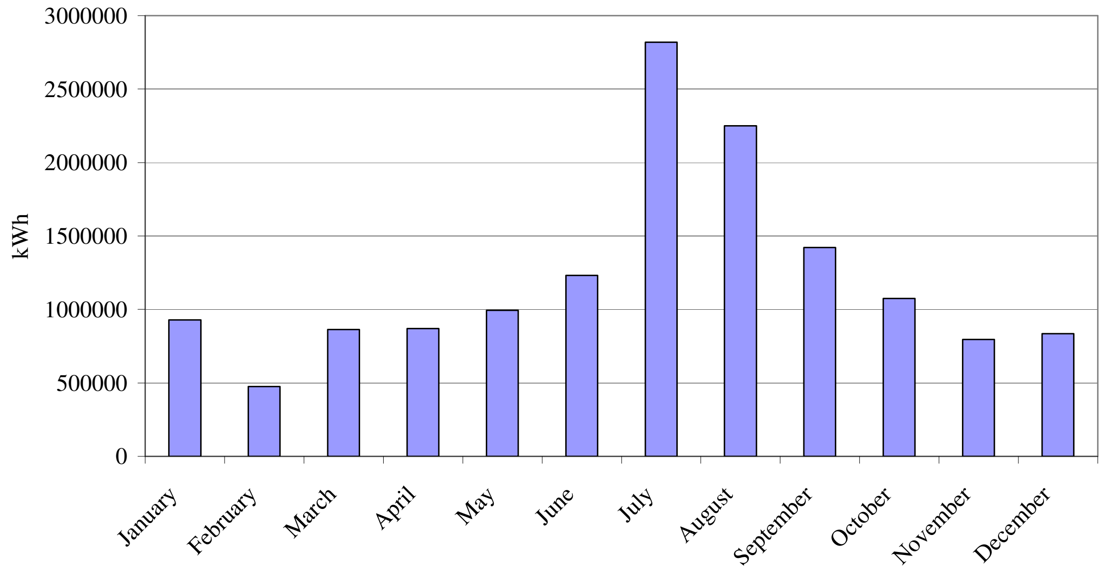


Figure 4.5. Total electricity consumption used for cooling found by regression

The electricity consumption values that are found with these formulas are compared in Table 4.3.

Table 4.3. The electricity consumption for cooling

	Average (2000-2004) Values (kWh)	Forecasted Values for 2005 Found by Regression (kWh)
January	373.724	928.852
February	289.907	475.304
March	356.160	863.036
April	260.271	869.233
May	365.429	993.091
June	568.232	1.230.439
July	1.445.931	2.819.419
August	1.490.005	2.249.216
September	1.202.935	1.421.333
October	717.494	1.073.558
November	391.014	794.786
December	251.189	834.950
Total	**7.712.288**	**14.553.217**

When the total electricity consumption for cooling is multiplied by the coefficient of performance value of the compression chillers, the result is the total annual cooling requirement of the hospital. The coefficient of performance figures of the compression chillers are given as five in the product specifications. However, this value is for ideal situations. For the real situation, the COP value is taken to be four. When the electricity consumption values obtained by averaging are considered, total annual cooling requirement can be found as 30.849.152 kWh, and this load can be supplied by the compression chillers in 2364 hours at full capacity. If this result is compared with the annual total capacity of the compression chillers by taking one year as 8760 hours, it can be seen that 27% of the total capacity has been used throughout the year. For the electricity consumption values obtained by regression, the cooling load becomes 58.212.868 kWh. This load can be supplied by the compression chillers in 4461 hours at full capacity. For this case, the load factor becomes 51%. The detailed results for required monthly cooling loads can be found in Appendix A.

4.3. Determining the Cooling Capacity Curve

When determining the capacity curve characteristics of the DERAH, it is assumed that the capacities are directly proportional to the consumption. Choosing a linear relation is due to the fact that only two values are known for the loads, which are the maximum capacity and the minimum capacity. The resulting curves can be seen in Figure 4.6 and Figure 4.7.

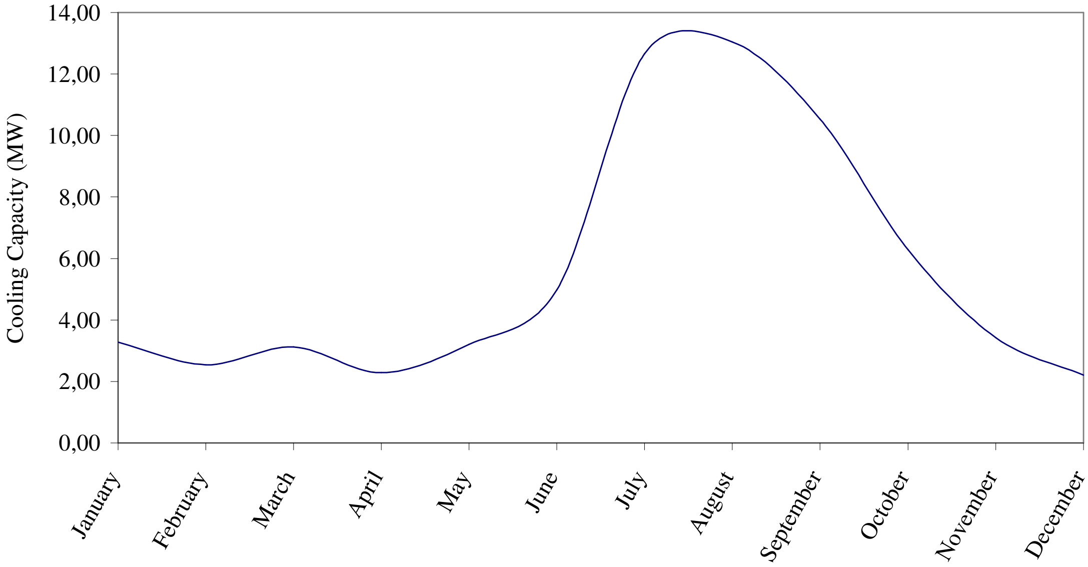


Figure 4.6. Cooling capacity curve found by averaging

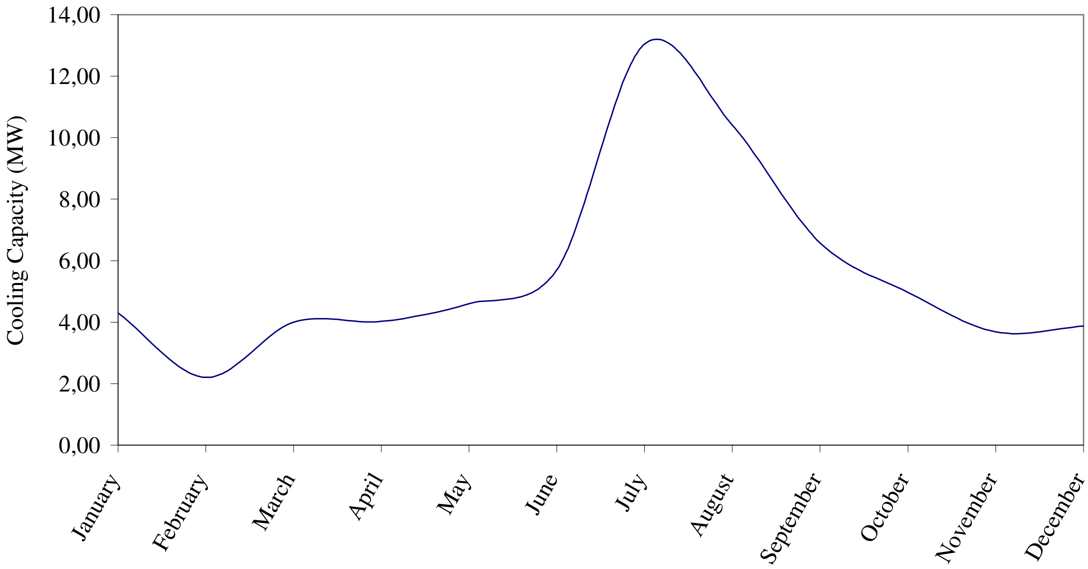


Figure 4.7. Cooling capacity curve found by regression

At this point, another capacity curve is found by using the daily temperature values of İzmir. For the weather data, the temperature values of 1993 has been used (Arısoy 2000), since it is chosen to be the characteristic year for İzmir. While making the calculations, it is assumed that the maximum capacity is used when the daily temperature value is maximum, 28°C, and the minimum capacity is used when the daily temperature is minimum, 4,4°C. For the other days, the capacity is directly proportional to temperature. After finding the daily capacity values, monthly capacity values are found by using the maximum capacity used during each month. The comparison of capacity curves is given in Figure 4.7.

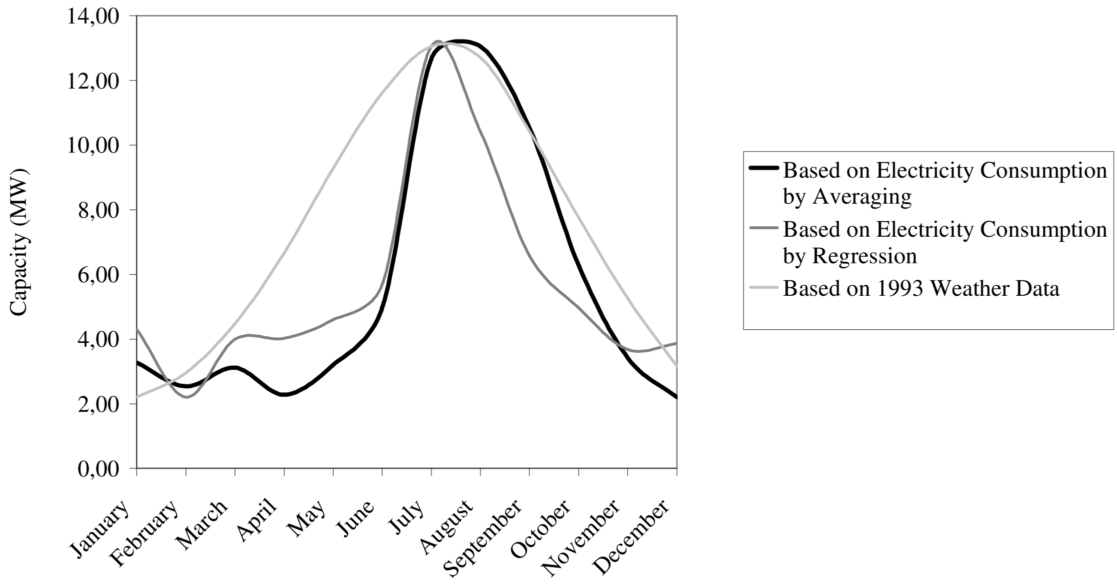


Figure 4.8. Comparison of capacity curves based on 1993 weather data and the actual electricity consumption values

As a result, since the capacities found by using actual data are generally lower than the capacities found by weather data, it is decided to use the actual data in calculations to keep on the safe side.

4.4. Determining the Total Annual Cost Incurred by the Compression Chillers

Total annual cooling costs incurred by the existing cooling system has been found by using the future worth method. In this method, monthly costs of managing the cooling system are transfered to the end of the year by applying a proper interest rate to them. For example, the cost for cooling in December added to the total cost directly since it is at the end of the year. However, for November, the interest occurred due to one month should also be added into calculations as well as the cost itself.

The currency of the costs, which are used in the calculations, are in US dollars. That's because the price of the absorption cooling machines are usually given in dollars. The interest rate that are going to be used in all cost calculations are taken as 8%, which is a usual value taken for dollar accounting (Park 2001). The unit electricity cost also has been converted to US dollars by taking 1 US dollar as 1,36 YTL and found to be 0,116 $/kWh. As a result, the annual operating cost of the existing chillers is appeared to be $925.068, when the average cooling loads are used. However, when the cooling loads that are found by linear regression have been used in the calculations, the result becomes $1.749.428, which is nearly twice the value found by the averaging. Also the unit cost of cooling of the hospital by compression chillers is found to be 0,029 $/kWh of cooling.

CHAPTER 5

ECONOMIC ANALYSIS OF ABSORPTION COOLING SYSTEMS

While choosing the absorption chiller, the aim is to minimize the costs. So, instead of supplying the maximum capacity, it would be better to supply a moderate capacity with a peaking system, which consists of the existing compression chillers. Instead of choosing a constant capacity, several capacities with several scenarios would be examined.

The annual cost incurred by the absorption cooling system can be divided into two parts. These are the costs incurred by the compression chillers due to peaking and the costs incurred by the absorption chiller. These costs will be examined seperately for each scenario.

For the costs incurred by the absorption chillers, there are also two possibilites depending on the pricing applied to the geothermal fluid. In the first possibility, the geothermal fluid can be priced on kWh basis while in the second one on m^3 basis. Since the used water will return at high temperatures, used energy during cooling would be very low with respect to the m^3 used. So, both pricing methods will be examined for each scenarios.

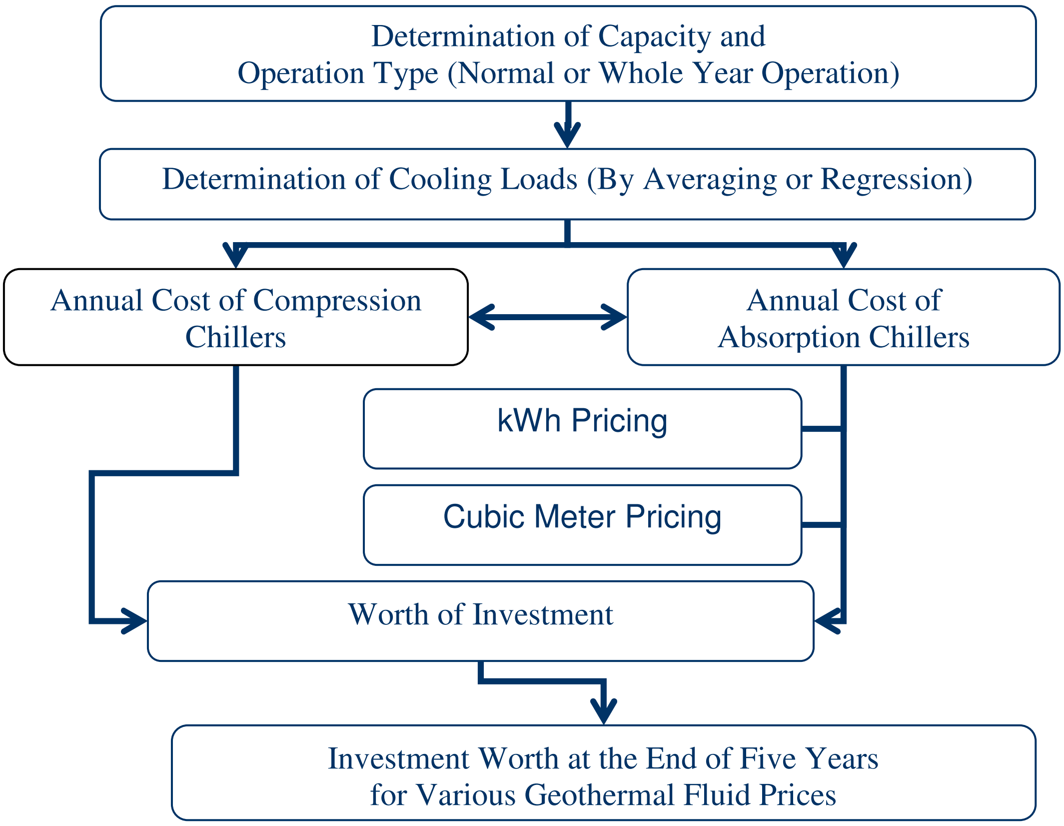
For the unit cost of the geothermal energy based on the cubic meter pricing method, the technical manager of DERAH suggests a value of 0,5698 $\$/m^3$. This suggestion is used, because the geothermal energy price is changing within a day, and the overall value is determined by a pre-programmed counter.

The unit cost of geothermal fluid based on kWh pricing has been found from this result by assuming that 1 m^3 of water can supply 56,53 kWh of energy, and the unit cost has been calculated as 0,01008 \$/kWh.

Since, the geothermal fluid is around 120°C, it is better to work with single-effect absorption chillers. To start with the calculations, the market is examined, and one of the largest capacity available in the market is determined to be 4,818 MW (YORK YIA-HW-14F3). It is decided to start the calculations with this machine and then extend the results to smaller machines, which have capacities of 2,288 MW (Thermax LT-52S) and 1,496 MW (Thermax LT-34S).

Calculations for absorption systems, initiate with the calculation of the cost of compression chillers due to peaking. Then the costs incurred by the absorption chillers has been calculated in two different ways based on pricing applied on geothermal fluid. These pricing options are kWh pricing and m^3 pricing. For the first absorption cooling machine which has a capacity of 4,818 MW, also an additional method has been tried based on finding the electricity consumption values by using linear regression. After that, the existing cooling system is compared with the absorption cooling system. For that comparison, the investment cost of the absorption cooling machine is taken to be the capital cost and the difference between the annual costs of the existing cooling system and the absorption cooling system is taken to be the annual income. These figures are then used to plot the investment worth through 30 years. As a final step, also the effect of change of geothermal fluid price on implementing an absorption cooling system has been found by plotting the investment worth at the end of five years for different geothermal fluid prices. Flow diagram of the calculations have been given in Table 5.1.

Table 5.1. Flow Diagram of the Calculations



5.1. An Absorption Chiller of 4,818 MW

The chosen device for this capacity is YORK YIA-HW-14F3. Basic specifications of this machine are given in Table 5.2.

Table 5.2. Basic specifications of York YIA-HW-14F3

Cooling Capacity (MW)	4,818
Water Inlet Temperature (^oC)	120
Water Exit Temperature (^oC)	104,4
Water Flow Rate (m^3/h)	400,5
COP	0,66
Capital Cost ($)	700.000

5.1.1. Determining the Costs Incurred by the Compression Chillers due to Peaking

To determine the total electricity consumption of the compression chiller throughout the year, it is necessary to find the consumption level at which the absorption chiller is not capable of supplying. For this aim, again it is assumed that load is proportional to electricity consumption. The peaking costs have to be calculated for loads obtained by averaging and regression seperately.

5.1.1.1. Peaking Cost by Using the Loads Obtained by Averaging

The maximum electricity consumption for cooling is 1.490.005 kWh for this case and, with a COP of four, the corresponding highest cooling load becomes 5.960.020 kWh. At this point, it is assumed that the absorption chiller is capable of supplying the whole load for the months, which have cooling requirement lower than 2.200.411 kWh (this value has been found by multiplying maximum cooling requirement, which is 5.960.020 kWh, by the ratio of absorption machine’s capacity to the maximum capacity). Above this level, the difference will be supplied by the compression chillers. The electricity consumption for compression chillers can be seen in Table 5.3.

Table 5.3. Electricity consumed by the compression chillers annually for the absorption machine of 4,818 MW for cooling loads obtained by averaging

	Electricity Use (kWh) For Compression Chillers
January	0
February	0
March	0
April	0
May	0
June	18.129
July	895.828
August	939.902
September	652.832
October	167.391
November	0
December	0
Total	**2.674.082**

To determine the costs incurred by the compression chillers, the future worth method has been used and the total cost is found to be \$318.995.

5.1.1.2. Peaking Cost by Using the Loads Obtained by Regression

The maximum electricity consumption for cooling is 2.819.419 kWh for this case and, with a COP of four, the corresponding highest cooling load becomes 11.277.676 kWh. At this point, it is assumed that the absorption chiller is capable of supplying the whole load for the months, which have cooling requirement lower than 4.163.666 kWh (this value has been found by multiplying maximum cooling requirement, which is 11.277.676 kWh, by the ratio of absorption machine's capacity to the maximum capacity). Above this level, the difference will be supplied by the compression chillers. The electricity consumption for compression chillers can be seen in Table 5.4.

Table 5.4. Electricity consumed by the compression chillers annually for the absorption machine of 4,818 MW for cooling loads obtained by regression

	Electricity Use (kWh) For Compression Chillers
January	0
February	0
March	0
April	0
May	0
June	189.522
July	1.778.502
August	1.208.300
September	380.417
October	32.642
November	0
December	0
Total	**3.589.383**

To determine the costs incurred by the compression chillers, the future worth method has been used and the total cost is found to be $429.599.

5.1.2. Determining the Costs Incurred by the Absorption Chiller

The examined machine has a capital cost of approximately $700.000. The variable costs are calculated for kWh basis and m^3 basis seperately. Also, for this machine, the loads found by regression has been used as well as the loads found by averaging.

5.1.2.1. Cooling Loads Found by Averaging

During the calculations conducted under this subtitle, the cooling loads that are going to be used are found by averaging the electricity consumption values for every month. The capacity of the absorption chiller is shown with the load curve found by averaging, in Figure 5.1.

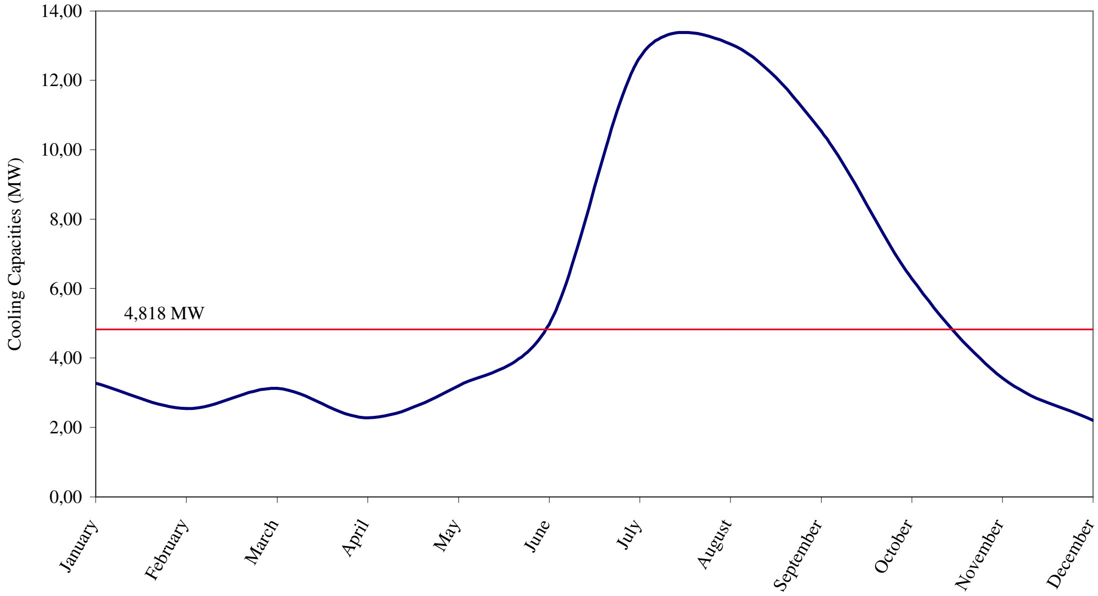


Figure 5.1. Capacity of the absorption chiller with respect to the capacity curve found by averaging for the absorption machine of 4,818 MW

In this figure the area under the line shows the load that is being supplied by the absorption chillers while the area above the line is supplied by compression chillers.

5.1.2.1.1. Pricing on kWh Basis

When the pricing is assumed to be on kWh basis, the procedure is the same as the one used in compression chillers. To find the required geothermal energy use of the absorption system, first the cooling loads have to be calculated. It is done by multiplying the monthly electricity consumption values with the COP of the existing compression chillers. Then the found cooling loads are divided by the COP of the absorption chiller to find the geothermal energy consumption. To find the cost incurred by the absorption chiller, this energy value is multiplied by the unit cost of water based on unit kWh. The found monthly costs are then transferred to the end of the year. Then the operation and maintenance costs are added to this value, which are given in the product datasheet supplied by the vendor for 2160 hours of operation and modified according to the obtained operating hour for the absorption chiller. A summary of the total cost of the absorption system is given in Table 5.5.

Table 5.5. Total annual cost of the absorption system in case of pricing on kWh basis or the absorption machine of 4,818 MW for cooling loads found by averaging

Electricity	109.322
Water Loss (Vaporization)	75.220
Chemicals	9.673
Maintenance	5.804
Per Machine ($)	200.020
Total Operational ($)	200.020
Geothermal Water ($)	317.243
Peaking Cost ($)	318.995
Annual Cost ($)	836.259

5.1.2.1.2. Pricing on m^3 Basis

When the pricing is assumed to be on m^3 basis, it is first necessary to find the monthly geothermal fluid consumption. For that aim, it is found that one m^3 of water that has been used in the absorption system has an energy content of 18,14 kWh (The temperature drop is 15,6°C, from 120°C to 104,4°C). Than, the monthly cooling loads are divided by this value to find the monthly water use on a m^3 basis. At this point, it is assumed that the water that is going to be used in cooling can also be used in heating purposes. The difference is that while normally the hot water used in heating is 110 °C, it will be below this temperature. As a result, the required geothermal fluid flowrate would be more than the existing values. The monthly geothermal fluid consumption is found by averaging the 2000 and 2003 water consumption values and it is assumed that the water, which returns from the absorption cooling system, can be available at 100°C. After this assumption, since heating system already consumes particular amount of water, annual additional geothermal fluid consumption for heating purposes have been calculated. For heating period, absorption system can be responsible from only this portion of the geothermal fluid consumption. So, to find the total geothermal consumption for cooling, these additional consumption have been used while for cooling period it is directly equal to the monthly geothermal fluid consumption. To find the cost incurred by the absorption chiller, these volume values are multiplied by the unit cost of water based on one m^3. The found monthly costs are then transferred to the end of the year. Then the operation and maintenance costs are added to this value, which are given in the product datasheet supplied by the vendor for 2160 hours of operation and modified according to the found operating hour for the absorption chiller. A summary of the total cost of the absorption system is given in Table 5.6.

Table 5.6. Total annual cost of the absorption system in case of pricing on m3 basis for the absorption machine of 4,818 MW for cooling loads found by averaging

Electricity	109.322
Water Loss (Vaporization)	75.220
Chemicals	9.673
Maintenance	5.804

Per Machine ($)	200.020

Total Operational ($)	200.020
Geothermal Water ($)	988.373
Peaking Cost ($)	318.995

Annual Cost ($)	1.507.389

5.1.2.2. Cooling Loads Found by Regression

During the calculations done under this topic, the cooling loads that are going to be used are found by applying a linear regression to the electricity consumption values for every month. The capacity of the absorption chiller is shown with the load curve found by regression, in Figure 5.2.

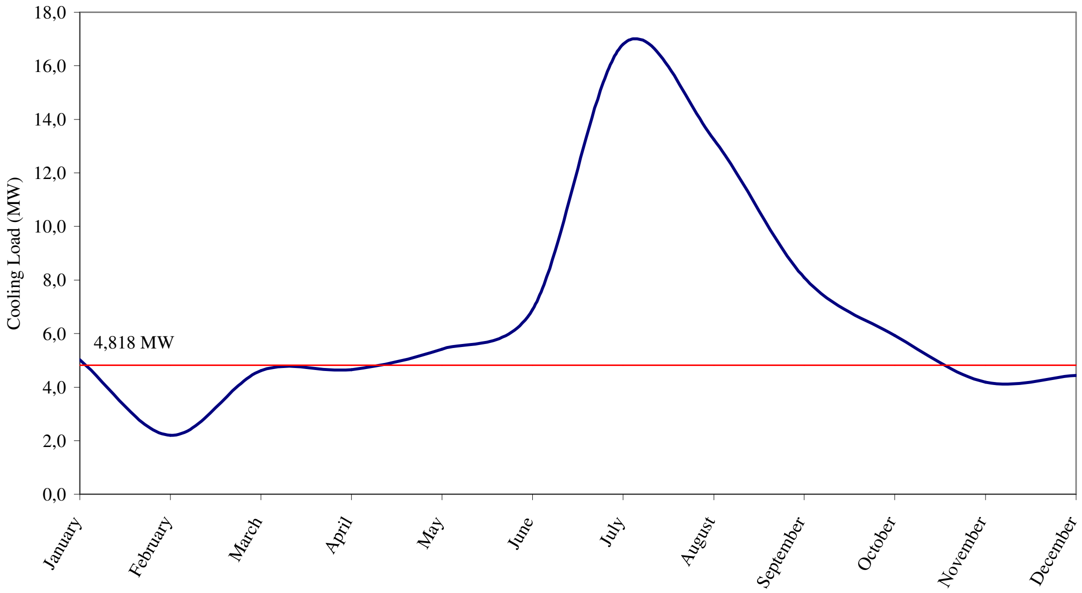


Figure 5.2. Capacity of the absorption chiller with respect to the capacity curve found by regression for the absorption machine of 4,818 MW

5.1.2.2.1. Pricing on kWh Basis

The procedure for calculating the prices are the same as the one, which involves the average values for cooling loads. The only difference is that the cooling loads are calculated by applying a linear regression to the electricity consumption values. The results are given in Table 5.7.

Table 5.7. Total annual cost of the absorption system in case of pricing on kWh basis for the absorption machine of 4,818 MW for cooling loads found by regression

Electricity	237.899
Water Loss (Vaporization)	163.691
Chemicals	21.050
Maintenance	12.630
Per Machine ($)	435.272
Total Operational ($)	435.272
Geothermal Water ($)	690.852
Peaking Cost ($)	429.599
Annual Cost ($)	1.555.723

5.1.2.2.2. Pricing on m^3 Basis

The procedure for calculating the prices are the same as the one, which involves the average values for cooling loads. The only difference is that the cooling loads are calculated by applying a linear regression to the electricity consumption values. The results are given in Table 5.8.

Table 5.8. Total annual cost of the absorption system in case of pricing on m3 basis for the absorption machine of 4,818 MW for cooling loads found by regression.

Electricity	237.899
Water Loss (Vaporization)	163.691
Chemicals	21.050
Maintenance	12.630
Per Machine ($)	435.272
Total Operational ($)	435.272
Geothermal Water ($)	2.152.354
Peaking Cost ($)	429.599
Annual Cost ($)	3.017.225

5.1.3. Comparing Absorption Cooling System with the Existing Cooling System

To compare two mutually exclusive alternatives, the differential costs incurred by the difference between the costs of these two alternatives are found. The sum of difference between the annual operating costs is the annual income and the difference between the capital costs is the worth of investment at the beginning of the project.

Costs are divided generally into two categories as the capital cost and the annual costs. It is assumed that the existing system won't be retired, and instead it would be held in the system as spare. So there is no capital cost for the existing system.

After finding the annual income and the capital cost, the discounted pay back period has been found for each alternative. Thus, the annual interest incurred due to the capital invested on the machine has been substracted from the annual income and the net income has been found. This value is substracted from the investment and the worth of the project at the end of the first year has been found. The worth of the following years are also calculated in the same way. The interest rate used for dollar is 8%.

5.1.3.1. Cooling Loads by Averaging

Throughout this headline, the calculations will be done by using the cooling loads found by averaging.

5.1.3.1.1. Pricing on kWh Basis

When the pricing for kWh basis have been used for the calculations, the annual cost for the absorption cooling system appears to be $836.259. This value is lower than the annual cost of the existing system, which is $925.068. The worth of investment for several years can be seen in Table 5.9.

Table 5.9. Worth of investment in case of pricing on kWh basis for the absorption machine of 4,818 MW for cooling loads found by averaging

	Net Income	Worth of Investment
0		-700.000
1	32.809	-667.190
2	35.434	-631.755
3	38269	-593.486
4	41.330	-552.155
5	44.637	-507.517
6	48.208	-459.309
7	52.065	-407.244
8	56.230	-351.013
9	60.728	-290.284
10	65.587	-224.697

From the results, it can be seen that the net annual income is positive. However this value is small compared to the initial investment. As a result, this absorption chiller can pay itself back in 13 years. Since this is a long period for this project to pay itself back, instead of choosing this alternative, maintaining the existing system seems to be a better choice. The behavior of the cash flow is given in Figure 5.3.

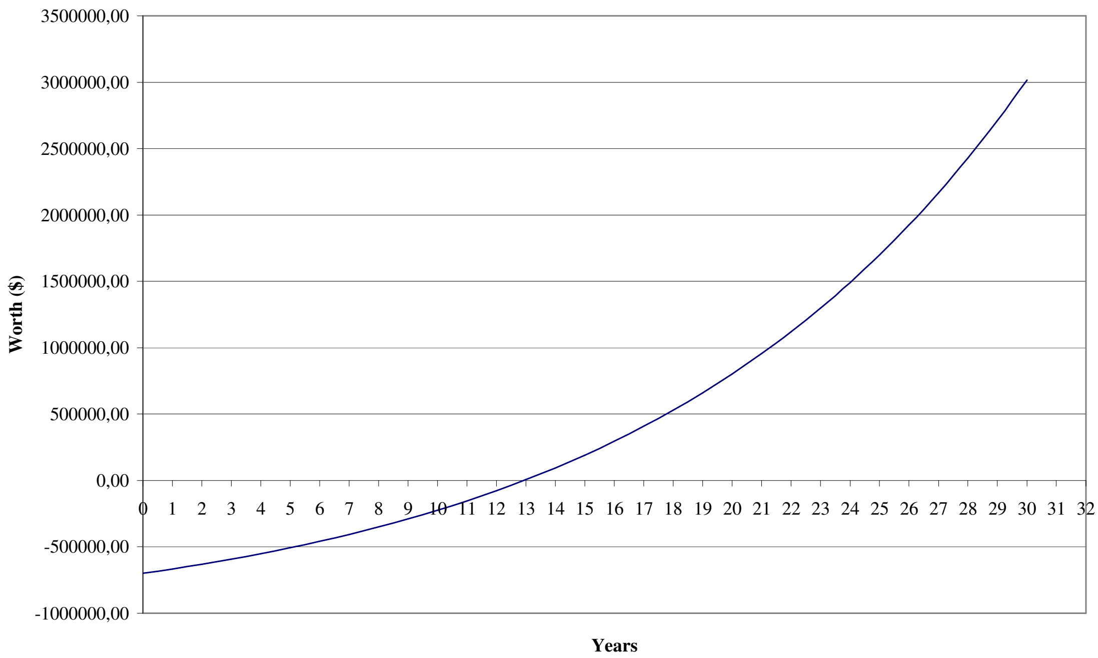


Figure 5.3. Worth of investment in case of pricing on kWh basis for the absorption machine of 4,818 MW for cooling loads found by averaging

To find the maximum geothermal fluid price that could make this project feasible, the investment worths at the end of five years have been determined and given in Table 5.10. It is assumed that, if the project can pay itself back in five years, it will be feasible.

Table 5.10. Investment Worth at the end of five years in case of pricing on kWh basis depending on the geothermal fluid price for the absorption machine of 4,818 MW for cooling loads found by averaging

Geothermal Fluid Price ($/kWh)	Investment Worth ($)	Pay Back Year
0	1.353.621	2
0,0025	892.131	3
0,005	430.641	4
0,0075	-30.849	6
0,01	-492.339	13
0,0125	-953.829	-
0,015	-1.415.319	-
0,0175	-1.876.809	-
0,02	-2.338.299	-

Also in Figure 5.4, the graph has been shown to represent the trend of investment worth depending on the changes in the geothermal fluid price.

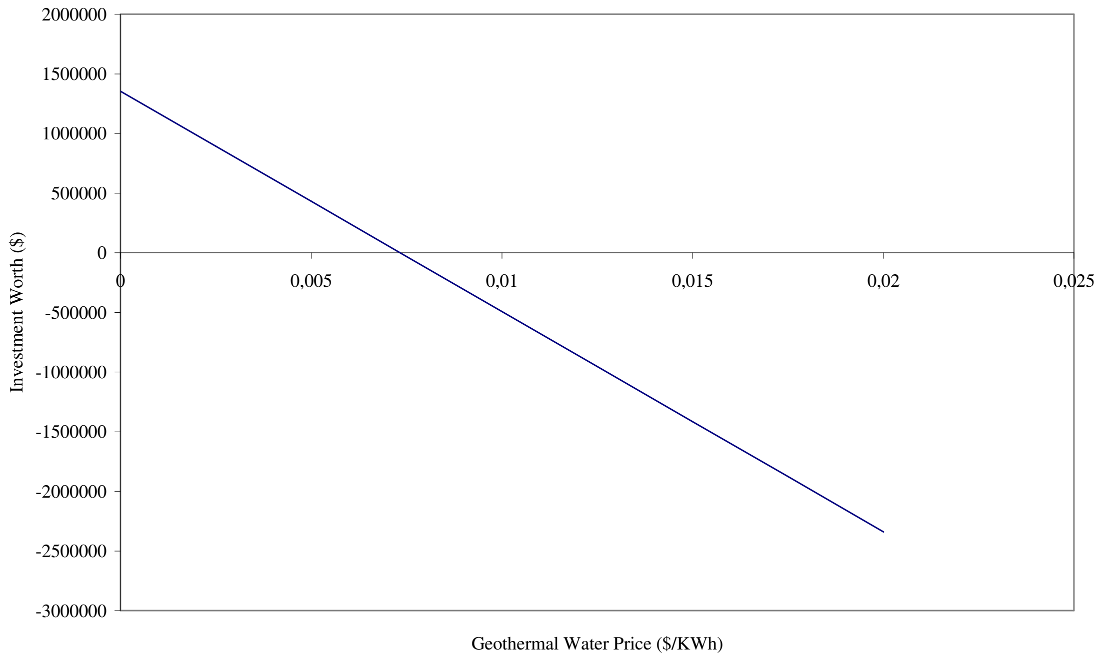


Figure 5.4. The investment worth in case of pricing on kWh basis at the end of five years with respect to geothermal fluid price for the absorption machine of 4,818 MW for cooling loads found by averaging

5.1.3.1.2. Pricing on m^3 Basis

When the pricing for m^3 basis have been used for the calculations, the annual cost for the absorption cooling system appears to be $1.507.389. This value is larger than the annual cost of the existing system, which is $925.068. The worth of investment for several years can be seen in Table 5.11.

Table 5.11. Worth of investment in case of pricing on m3 basis for the absorption machine of 4,818 MW for cooling loads found by averaging

	Net Income	Worth of Investment
0		-700.000
1	-638.320	-1.338.320
2	-689.385	-2.027.706
3	-744.536	-2.772.242
4	-804.099	-3.576.342
5	-868.427	-4.444.770
6	-937.901	-5.382.672
7	-1.012.934	-6.395.606
8	-1.093.968	-7.489.574
9	-1.181.486	-8.671.061
10	-1.276.005	-9.947.066

The net annual income is negative, since the annual cost of the absorption cooling system is smaller than the annual cost of the existing system. This alternative cannot pay itself back, so leaving the existing system instead of applying this alternative is better. The behavior of the cash flow is given in Figure 5.5.

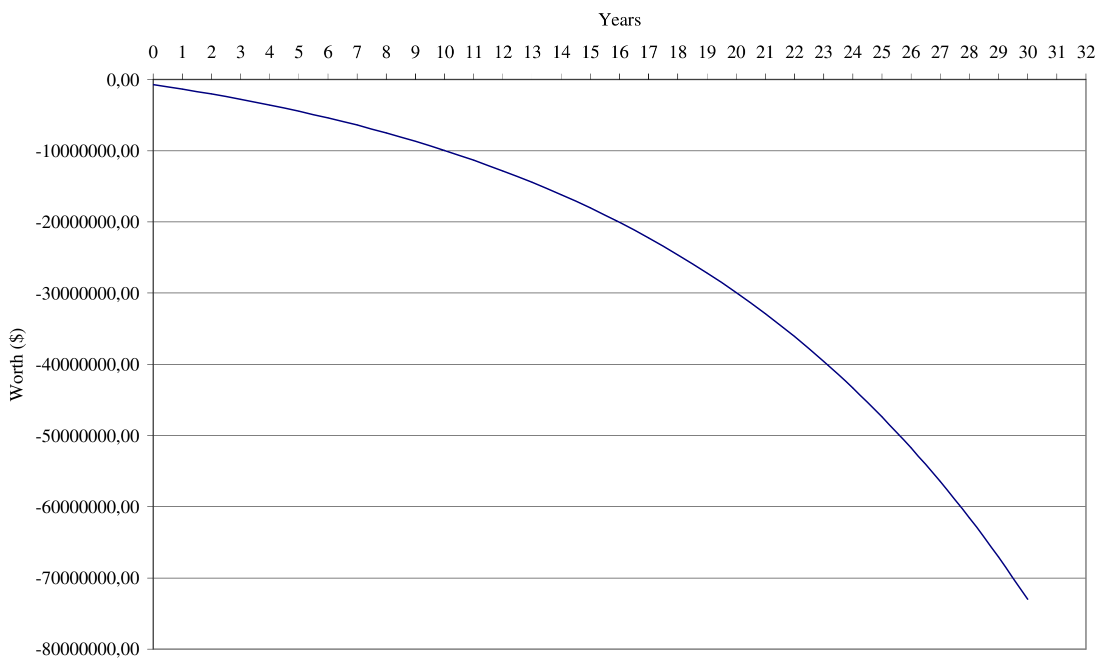


Figure 5.5. Worth of investment in case of pricing on m3 basis for the absorption machine of 4,818 MW for cooling loads found by averaging

To find the maximum geothermal fluid price that could make this project feasible, the investment worths at the end of five years have been determined and given in Table 5.12.

Table 5.12. Investment Worth in case of pricing on m3 basis at the end of five years depending on the geothermal fluid price for the absorption machine of 4,818 MW for cooling loads found by averaging

Geothermal Water Price ($/m^3)	Investment Worth ($)	Pay Back Year
0	1.302.091	2
0,1	284.472	4
0,2	-733.146	-
0,3	-1.750.765	-
0,4	-2.768.384	-
0,5	-3.786.003	-
0,6	-4.803.621	-
0,7	-5.821.240	-
0,8	-6.838.859	-

Also in Figure 5.6, the graph has been shown to represent the trend of investment worth depending on the changes in the geothermal fluid price.

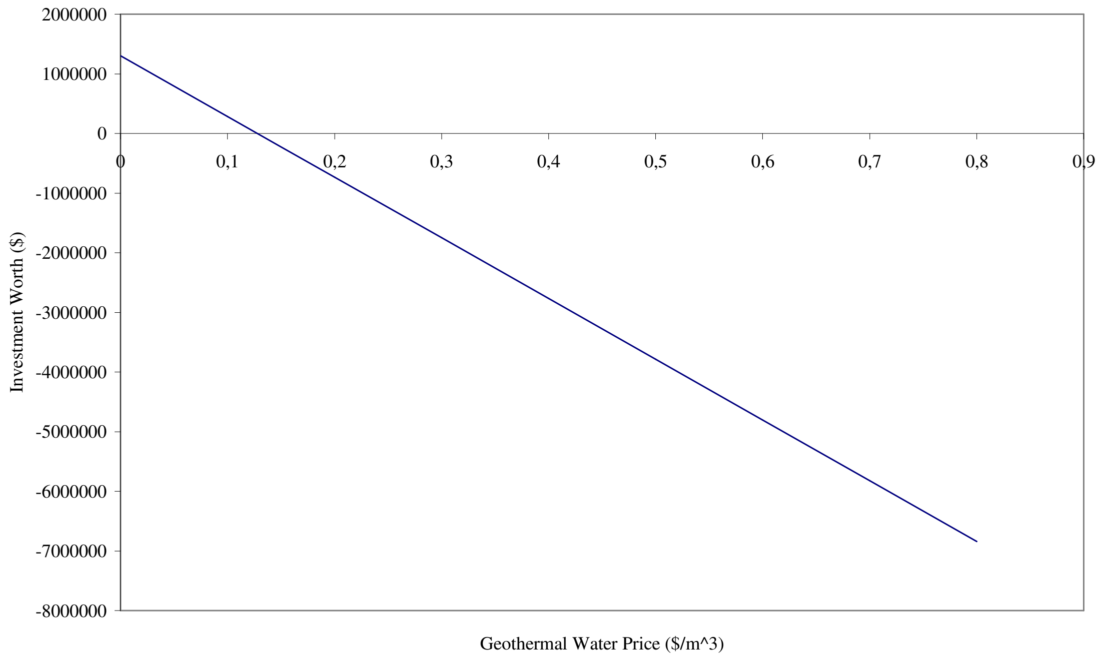


Figure 5.6. The investment worth in case of m3 pricing at the end of five years with respect to geothermal fluid price for the absorption machine of 4,818 MW for cooling loads found by averaging

5.1.3.2. Cooling Loads by Regression

When the cooling loads calculated by using linear regression method are used, it can be seen that the annual working hours of the absorption cooling machine appears to be 9.094 hours, which is more than the total hours of a year. This is because of the fact that the cooling loads are very high with respect to the capacity figures and this makes the assumptions that the cooling capacity is directly proportional with the electricity used for cooling invalid. The main reason here is the fact that the minimum and maximum cooling loads cannot be supplied with the existing minimum and maximum cooling capacities. Since results are not consistent, they are only presented for this machine and not the other absorption cooling machines throughout the thesis.

5.1.3.2.1. Pricing on kWh Basis

When the pricing for kWh basis have been used for the calculations, the annual cost for the absorption cooling system appears to be $1.555.723. This value is larger than the annual cost of the existing system, which is $1.749.428. These results are considerably larger than the results found by averaging the cooling loads. The worth of investment for several years can be seen in Table 5.13.

Table 5.13. Worth of investment in case of pricing on kWh basis for the absorption machine of 4,818 MW for cooling loads found by regression

	Net Income	Worth of Investment
0		-700.000
1	137.705	-562.294
2	148.722	-413.571
3	160.620	-252.951
4	173.469	-79.481
5	187.347	107.865
6	202.335	310.201
7	218.522	528.723
8	236.003	764.726
9	254.884	1.019.611
10	275.274	1.294.885

From the results, it can be seen that the net annual income is positive and the pay back period of this alternative appears to be five years. So, this alternative seems to be economical. The behavior of the cash flow is given in Figure 5.7.

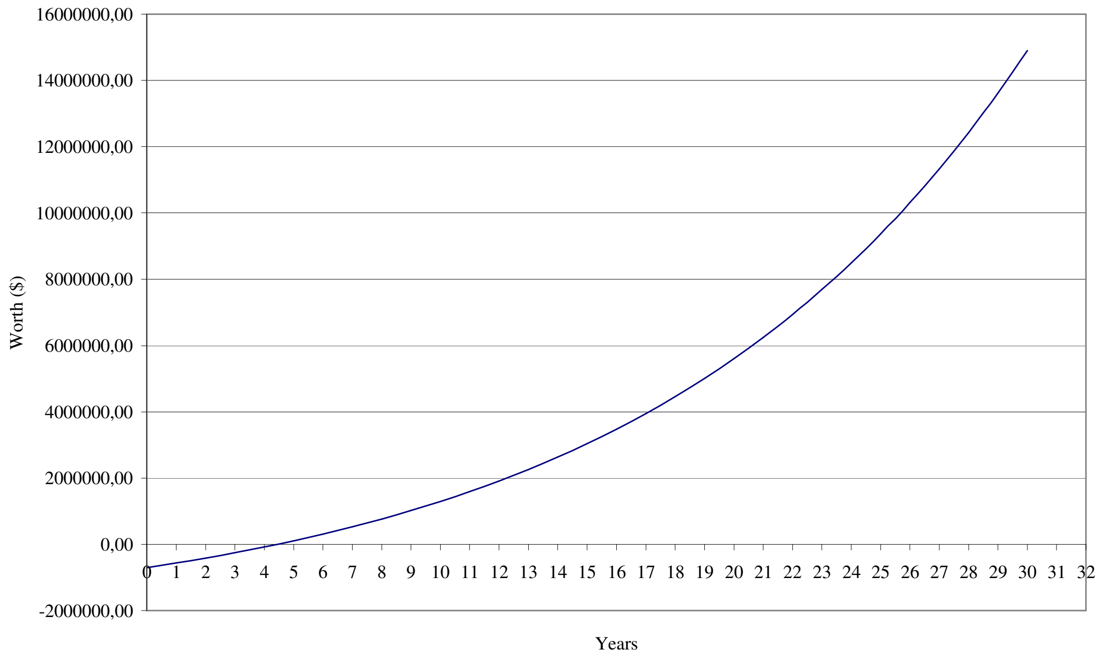


Figure 5.7. Worth of investment in case of kWh pricing for the absorption machine of 4,818 MW for cooling loads found by regression

To find the maximum geothermal fluid price that could make this project feasible, the investment worths at the end of five years have been determined and given in Table 5.14.

Table 5.14. Investment Worth in case of kWh pricing at the end of five years depending on the geothermal fluid price for the absorption machine of 4,818 MW for cooling loads found by regression

Geothermal Water Price	Investment Worth	Pay Back Year
0	4.160.819	1
0,0025	3.155.844	2
0,005	2.150.869	2
0,0075	1.145.895	3
0,01	140.920	5
0,0125	-864.055	-
0,015	-1.869.029	-
0,0175	-2.874.004	-
0,02	-3.878.979	-

Also in Figure 5.8, the graph has been shown to represent the trend of investment worth depending on the changes in the geothermal fluid price.

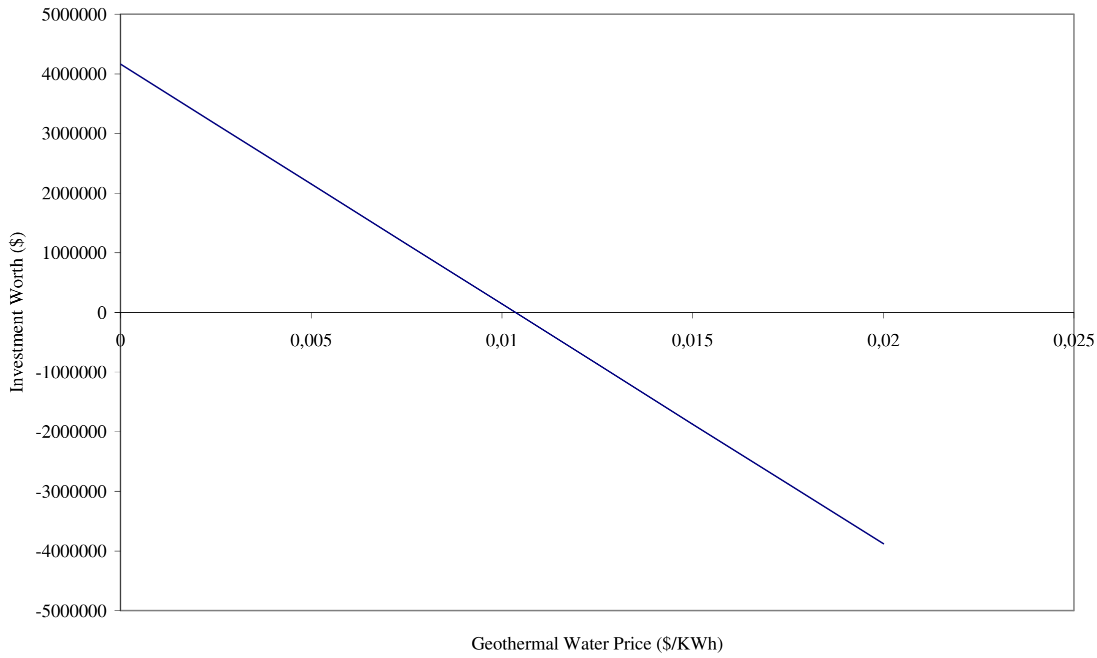


Figure 5.8. The investment worth in case of kWh pricing at the end of five years with respect to geothermal fluid price for the absorption machine of 4,818 MW for cooling loads found by regression

5.1.3.2.2. Pricing on m^3 Basis

When the pricing for m^3 basis have been used for the calculations, the annual cost for the absorption cooling system appears to be $3.017.225. This value is again larger than the annual cost of the existing system, which is $1.749.428. The worth of investment for several years can be seen in Table 5.15.

Table 5.15. Worth of investment in case of pricing on m3 basis for the absorption machine of 4,818 MW for cooling loads found by regression

	Net Income	Worth of Investment
0		-700.000
1	-1.323.796	-2.023.796
2	-1.429.699	-3.453.496
3	-1.544.075	-4.997.572
4	-1.667.602	-6.665.174
5	-1.801.010	-8.466.184
6	-1.945.091	-10.411.275
7	-2.100.698	-12.511.973

The net annual income is negative, since the annual cost of absorption cooling system is more than the annual cost of the existing system. This alternative cannot pay itself back, so leaving the existing system instead of applying this alternative is better. The behavior of the cash flow is given in Figure 5.9.

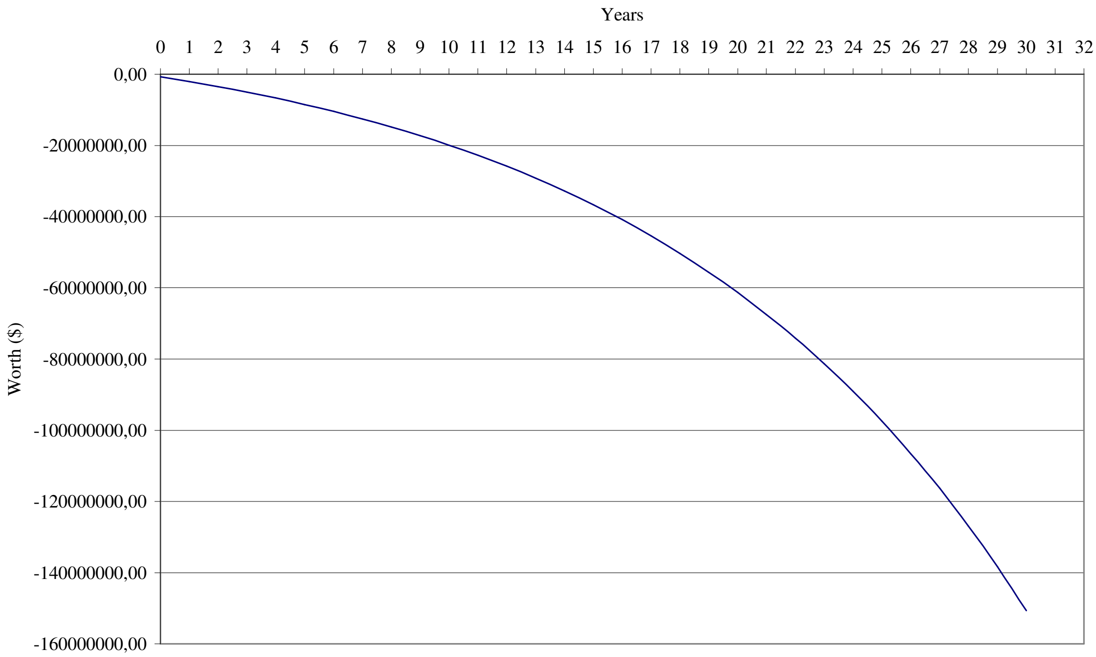


Figure 5.9. Worth of investment in case of m3 pricing for the absorption machine of 4,818 MW for cooling loads found by regression

To find the maximum geothermal fluid price that could make this project feasible, the investment worths at the end of five years have been determined and given in Table 5.16.

Table 5.16. Investment Worth in case of m3 pricing at the end of five years depending on the geothermal fluid price for the absorption machine of 4,818 MW for cooling loads found by regression

Geothermal Water Price ($/m^3)	Investment Worth ($)	Pay Back Year
0	3.591.963	1
0,1	1.375.921	2
0,2	-840.120	-
0,3	-3.056.161	-
0,4	-5.272.203	-
0,5	-7.488.244	-
0,6	-9.704.285	-
0,7	-11.920.326	-
0,8	-14.136.368	-

Also in Figure 5.10, the graph has been shown to represent the trend of investment worth depending on the changes in the geothermal fluid price.

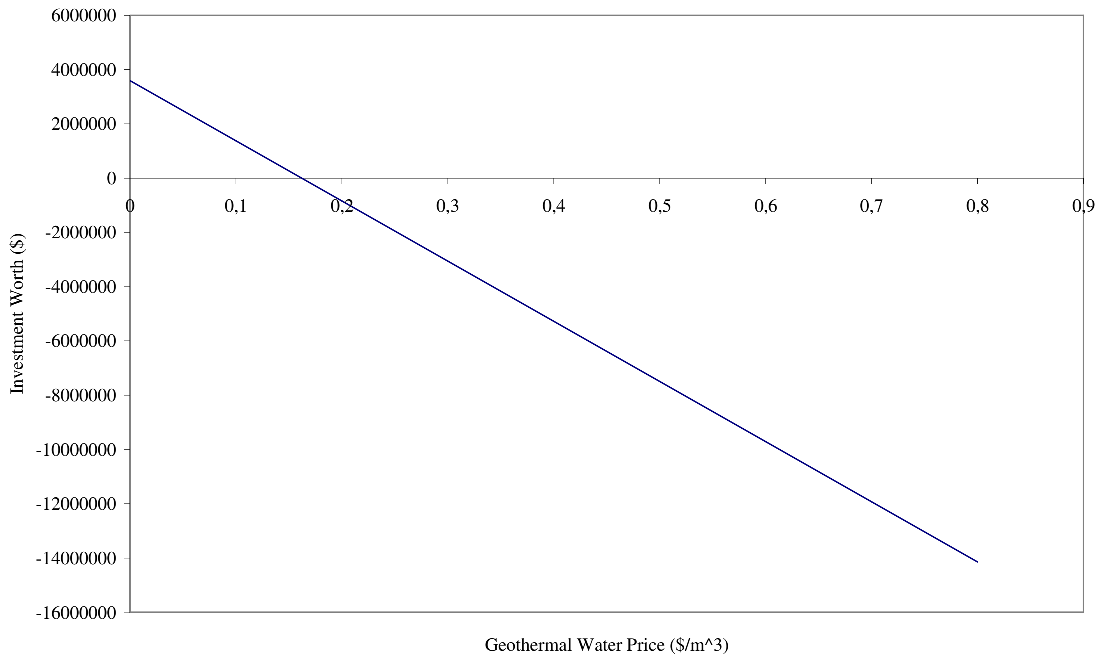


Figure 5.10. The investment worth in case of m3 at the end of five years with respect to geothermal fluid price for the absorption machine of 4,818 MW for cooling loads found by regression.

5.2. An Absorption Chiller of 2,288 MW

The chosen device for this capacity is THERMAX LT-52S. Basic specifications of this machine can be seen in Table 5.17.

Table 5.17. Basic specifications of THERMAX LT-52S

Cooling Capacity (MW)	2,288
Water Inlet Temperature (^{o}C)	110
Water Exit Temperature (^{o}C)	95
Water Flow Rate (m^3/h)	194
COP	0,71
Capital Cost ($)	394.046

The procedure of calculations is the same as the first absorption machine. So, from now on, only the results will be given. Also, since the cooling loads found by regression appears to be invalid in physical sense, only the loads found by averaging will be considered.

5.2.1. Determining the Costs Incurred by the Compression Chillers due to Peaking

Table 5.18. Electricity consumed by the compression chillers annually for an absorption chiller of 2,288 MW

	Electricity Use for Compression Chillers (kWh)
January	112.487
February	28.671
March	94.923
April	0
May	104.192
June	306.996
July	1.184.694
August	1.228.768
September	941.698
October	456.257
November	129.777
December	0
Total	**4.588.468**

To determine the costs incurred by the compression chillers, the future worth method has been used and the total cost is found to be \$548.505.

5.2.2. Determining the Costs Incurred by the Absorption Chiller

The examined machine has a capital cost of approximately \$394.046. The variable costs are calculated for kWh basis and m^3 basis.

5.2.2.1. Cooling Loads Found by Averaging

During the calculations done under this topic, the cooling loads that are going to be used are found by averaging the electricity consumption values for every month. The capacity of the absorption chiller is shown with the load curve found by averaging, in Figure 5.11.

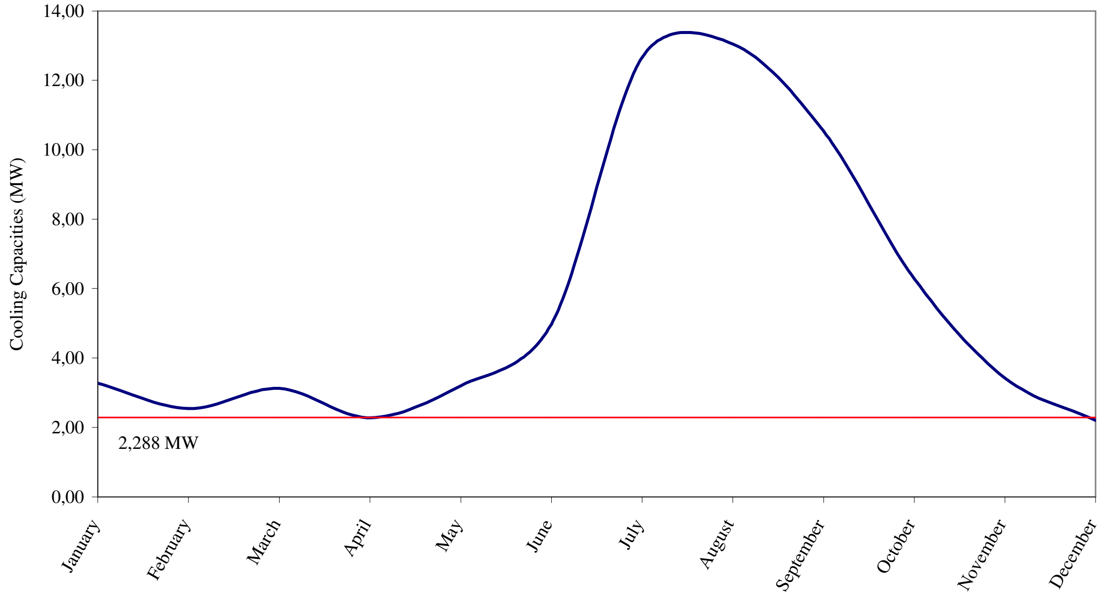


Figure 5.11. Capacity of the absorption chiller with respect to the capacity curve found by averaging for an absorption chiller of 2,288 MW

In this figure the area under the line shows the load that is being supplied by the absorption chillers while the area above the line is supplied by compression chillers.

5.2.2.1.1. Pricing on kWh Basis

Table 5.19. Total annual cost of the absorption system in case of pricing on kWh basis for an absorption chiller of 2,288 MW for cooling loads found by averaging.

Electricity	7.163
Water Loss (Vaporization)	46.637
Chemicals	5.998
Maintenance	3.599
Per Machine ($)	63.396
Total Operational ($)	63.396
Geothermal Water ($)	184.110
Peaking Cost ($)	548.505
Annual Cost ($)	796.011

5.2.2.1.2. Pricing on m^3 Basis

Table 5.20. Total annual cost of the absorption system in case of pricing on m3 basis for an absorption chiller of 2,288 MW for cooling loads found by averaging.

Electricity	7.163
Water Loss (Vaporization)	46.637
Chemicals	5.998
Maintenance	3.599

Per Machine ($)	63.396

Total Operational ($)	63.396
Geothermal Water ($)	447.190
Peaking Cost ($)	548.505

Annual Cost ($)	1.059.091

5.2.3. Comparing Absorption Cooling System with the Existing Cooling System

The procedure used for this machine is the same as the first machine except that the loads found by regression won't be used in the calculations.

5.2.3.1. Cooling Loads by Averaging

Throughout this headline, the calculations will be done by using the cooling loads found by averaging.

5.2.3.1.1. Pricing on kWh Basis

When the pricing for kWh basis have been used for the calculations, the annual cost for the absorption cooling system appears to be $796.011. This value is lower than the annual cost of the existing system, which is $925.068. The worth of investment for several years can be seen in Table 5.21.

Table 5.21. Worth of investment in case of pricing on kWh basis for an absorption chiller of 2,288 MW for cooling loads found by averaging.

	Net Income	Worth of Investment
0		-394.046
1	97.533	-296.512
2	105.335	-191.177
3	113.762	-77.414
4	122.863	45.449
5	132.692	178.142
6	143.308	321.450
7	154.773	476.223
8	167.154	643.378
9	180.527	823.906
10	194.969	1.018.875

From the results, it can be seen that the net annual income is positive. So, choosing this alternative seems to be more economical than maintaining the existing system. The behavior of the cash flow is given in Figure 5.12.

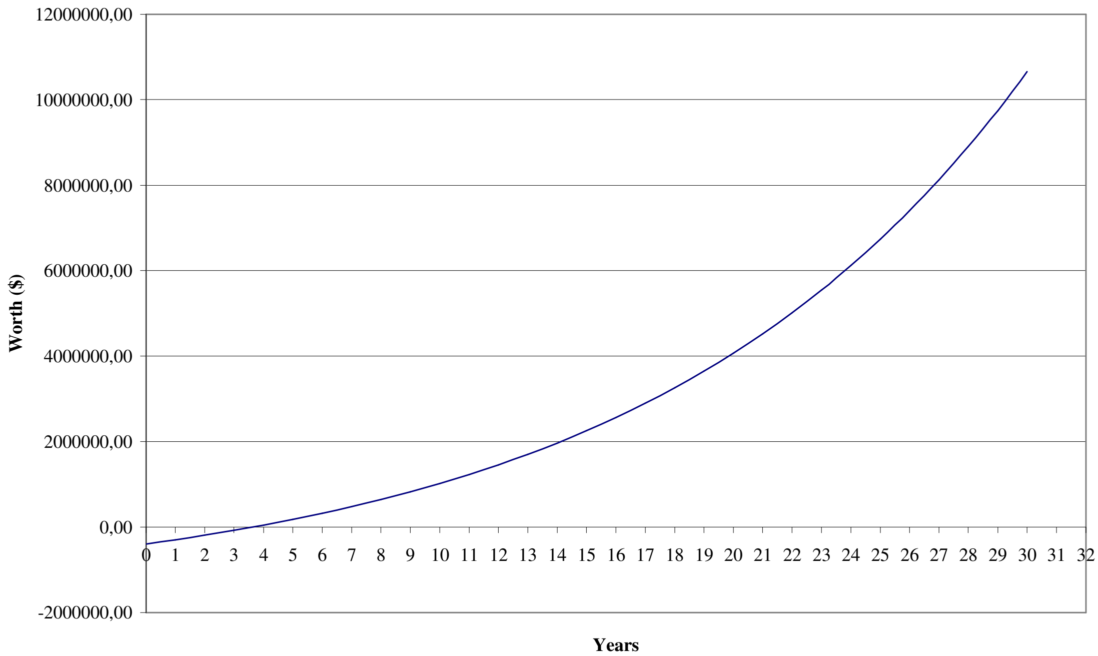


Figure 5.12. Worth of investment in case of pricing on kWh basis for an absorption chiller of 2,288 MW for cooling loads found by averaging.

To find the maximum geothermal fluid price that could make this project feasible, the investment worths at the end of five years have been determined and given in Table 5.22.

Table 5.22. Investment Worth at the end of five years in case of pricing on kWh basis depending on the geothermal fluid price for an absorption chiller of 2,288 MW for cooling loads found by averaging.

Geothermal Water Price ($/kWh)	Investment Worth ($)	Pay Back Year
0	1.226.836	2
0,0025	959.013	2
0,005	691.190	3
0,0075	423.367	3
0,01	155.544	4
0,0125	-112.279	7
0,015	-380.103	35
0,0175	-647.926	-
0,02	-915.749	-

Also in Figure 5.13, the graph has been shown to represent the trend of investment worth depending on the changes in the geothermal fluid price.

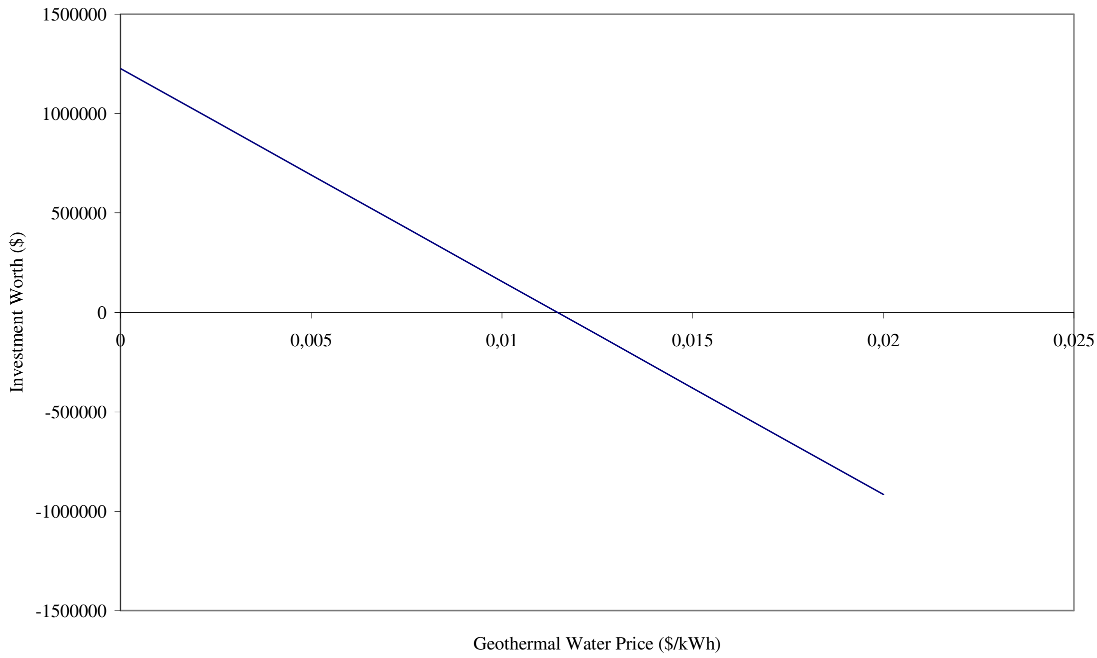


Figure 5.13. The investment worth at the end of five years in case of kWh pricing with respect to geothermal fluid price for an absorption chiller of 2,288 MW for cooling loads found by averaging.

5.2.3.1.2. Pricing on m^3 Basis

When the pricing for m^3 basis have been used for the calculations, the annual cost for the absorption cooling system appears to be $1.059.091. This value is larger than the annual cost of the existing system, which is $925.068. The worth of investment for several years can be seen in Table 5.23.

Table 5.23. Worth of investment in case of pricing on m3 basis for an absorption chiller of 2,288 MW for cooling loads found by averaging.

	Net Income	Worth of Investment
0		-394.046
1	-165.546	-559.593
2	-178.790	-738.383
3	-193.093	-931.477
4	-208.541	-1.140.018
5	-225.224	-1.365.243
6	-243.242	-1.608.485
7	-262.701	-1.871.187
8	-283.718	-2.154.905
9	-306.415	-2.461.321
10	-330.928	-2.792.249

The net annual income is negative. This alternative cannot pay itself back, so leaving the existing system instead of applying this alternative is better. The behavior of the cash flow is given in Figure 5.14.

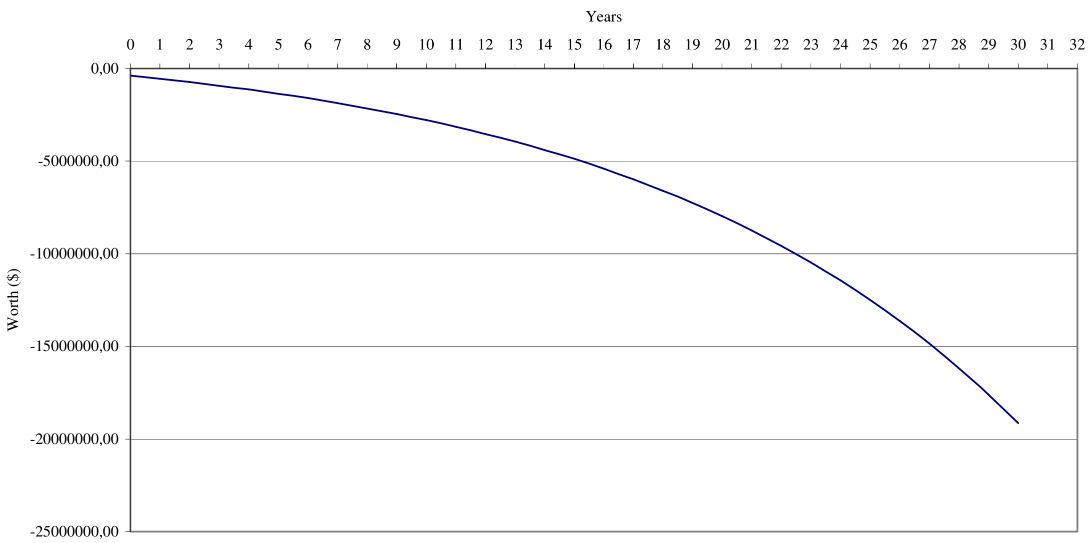


Figure 5.14. Worth of investment in case of pricing on m3 basis for an absorption chiller of 2,288 MW for cooling loads found by averaging.

To find the maximum geothermal fluid price that could make this project feasible, the investment worths at the end of five years have been determined and given in Table 5.24.

Table 5.24. Investment Worth at the end of five years in case of pricing on m3 basis depending on the geothermal fluid price for an absorption chiller of 2,288 MW for cooling loads found by averaging.

Geothermal Water Price ($/m^3)	Investment Worth ($)	Pay Back Year
0	1.258.244	2
0,1	797.821	2
0,2	337.399	3
0,3	-123.023	7
0,4	-583.446	-
0,5	-1.043.868	-
0,6	-1.504.291	-
0,7	-1.964.713	-
0,8	-2.425.135	-

Also in Figure 5.15, the graph has been shown to represent the trend of investment worth depending on the changes in the geothermal fluid price.

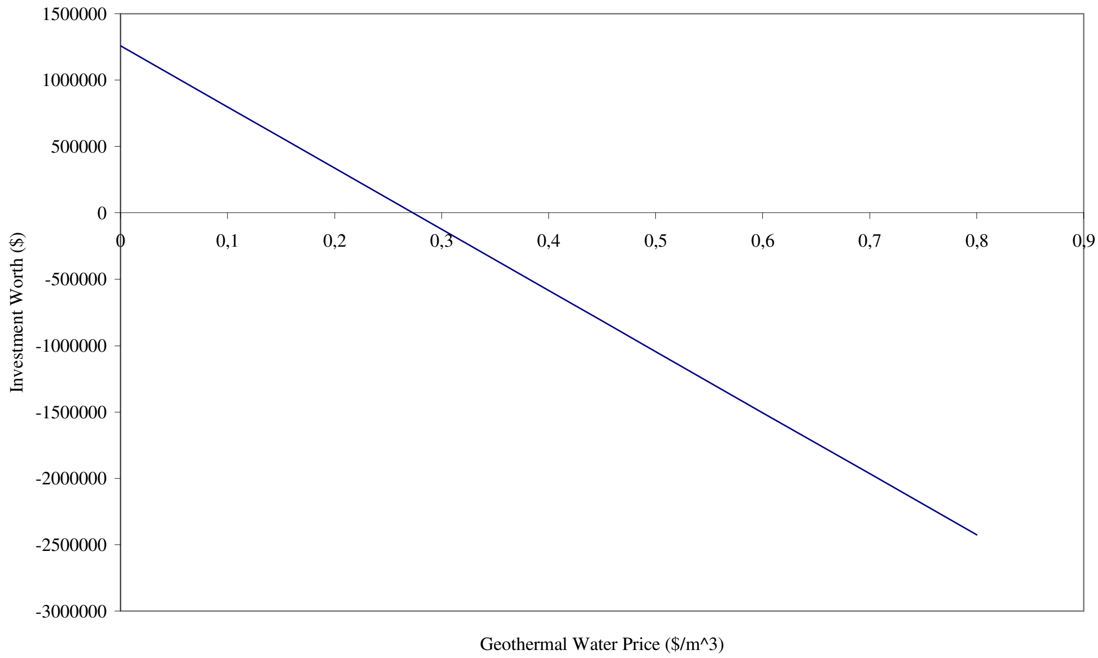


Figure 5.15. The investment worth at the end of five years in case of pricing on m3 basis with respect to geothermal fluid price for an absorption chiller of 2,288 MW for cooling loads found by averaging.

5.3. An Absorption Chiller of 2,288 MW When Whole Year Operation is Considered

Throughout the calculation method applied for a 4,818 MW machine, it was assumed that the machine would have a low use ratio since it has a considerably high capacity when it is compared with the minimum capacity of the hospital. Although this assumption may be hold for that machine, it is not as much as consistent with the 2,288 MW machine, since its capacity is nearly the same as the minimum capacity. For that aim, it is decided to conduct a further analysis.

In this analysis, first the total annual cooling load will be found. Then, it will be thought that the machine will work at 2,2 MW throughout the whole year and supplies nearly the maximum amount of cooling that it could supply. The difference between the total load and the maximum load will be supplied by the compression chillers. The costs are considered on annual basis instead of monthly basis in this method so that the results can be found by multiplying the total annual consumption of electricity and geothermal fluid by the unit price of electricity and geothermal fluid.

The chosen device for this capacity is again THERMAX LT-52S. Basic specifications of this machine can be seen in Table 5.17.

5.3.1. Determining the Costs Incurred by the Compression Chillers due to Peaking

The total cooling load for the hospital is 30.849.155 kWh. An absorption chiller with a capacity of 2,2 MW can supply an annual load of 19.272.000 kWh. So the compression chillers should supply a cooling load of 11.577.155 kWh throughout the year. This cooling load leads to an electricity comsumption of 2.894.288 kWh. To find the annual cost of the compression chillers, this value is multiplied by the unit price of the electricity. The result is found as 336.248$.

5.3.2. Determining the Costs Incurred by the Absorption Chiller

The examined machine has a capital cost of approximately $394.046. The variable costs are calculated for kWh basis and m^3 basis.

5.3.2.1. Cooling Loads Found by Averaging

During the calculations done under this topic, the cooling loads that are going to be used are found by averaging the electricity consumption values for every month.

5.3.2.1.1. Pricing on kWh Basis

To find the annual geothermal fluid cost of absorption cooling machine, the annual cooling supplied by the machine, which is 19.272.000 kWh, is multiplied by the unit price of geothermal fluid in case of kWh pricing. For maintenance cost, since those costs are given for 2160 working hours, they are modified for 8760 working hours, by multiplying them with the ratio of the working hours, which is nearly 4. The results are given in Table 5.25.

Table 5.25. Total annual cost of the absorption system in case of pricing on kWh basis for an absorption chiller of 2,288 MW for cooling loads found by averaging, whole year operation.

Electricity	11.500
Water Loss (Vaporization)	74.880
Chemicals	9.630
Maintenance	5.778
Per Machine ($)	101.787
Total Operational ($)	101.787
Geothermal Water ($)	194.305
Peaking Cost ($)	336.248
Annual Cost ($)	632.340

5.3.2.1.2. Pricing on m^3 Basis

When pricing is based on m^3 basis, the only difference is that the annual cost is found by using the annual geothermal fluid consumption value of the absorption cooling machine. The results are given in Table 5.26.

Table 5.26. Total annual cost of the absorption system in case of pricing on m3 basis for an absorption chiller of 2,288 MW for cooling loads found by averaging, whole year operation.

Electricity	11.500
Water Loss (Vaporization)	74.880
Chemicals	9.630
Maintenance	5.778
Per Machine ($)	101.787
Total Operational ($)	101.787
Geothermal Water ($)	654.562
Peaking Cost ($)	336.248
Annual Cost ($)	1.092.597

5.3.3. Comparing Absorption Cooling System with the Existing Cooling System

The procedure used for comparing this machine with the compression cooling system is the same as the first machine except that the loads found by regression won't be used in the calculations.

5.3.3.1. Cooling Loads by Averaging

Throughout this headline, the calculations will be done by using the cooling loads found by averaging.

5.3.3.1.1. Pricing on kWh Basis

When the pricing for kWh basis have been used for the calculations, the annual cost for the absorption cooling system appears to be $632.340. This value is lower than the annual cost of the existing system, which is $925.068. The worth of investment for several years can be seen in Table 5.27.

Table 5.27. Worth of investment in case of pricing on kWh basis for an absorption chiller of 2,288 MW for cooling loads found by averaging, whole year operation.

	Net Income	Worth of Investment
0		-394.046
1	261.204	-132.8.41
2	282.100	149.258
3	304.668	453.927
4	329.042	782.969
5	355.365	1.138.335
6	383.794	1.522.129
7	414.498	1.936.628
8	447.658	2.384.286
9	483.470	2.867.757
10	522.148	3.389.906

The net annual income is positive in this case. So this alternative can pay itself back. As a result, the discounted pay back is found to be two years. The behavior of the cash flow is given in Figure 5.16.

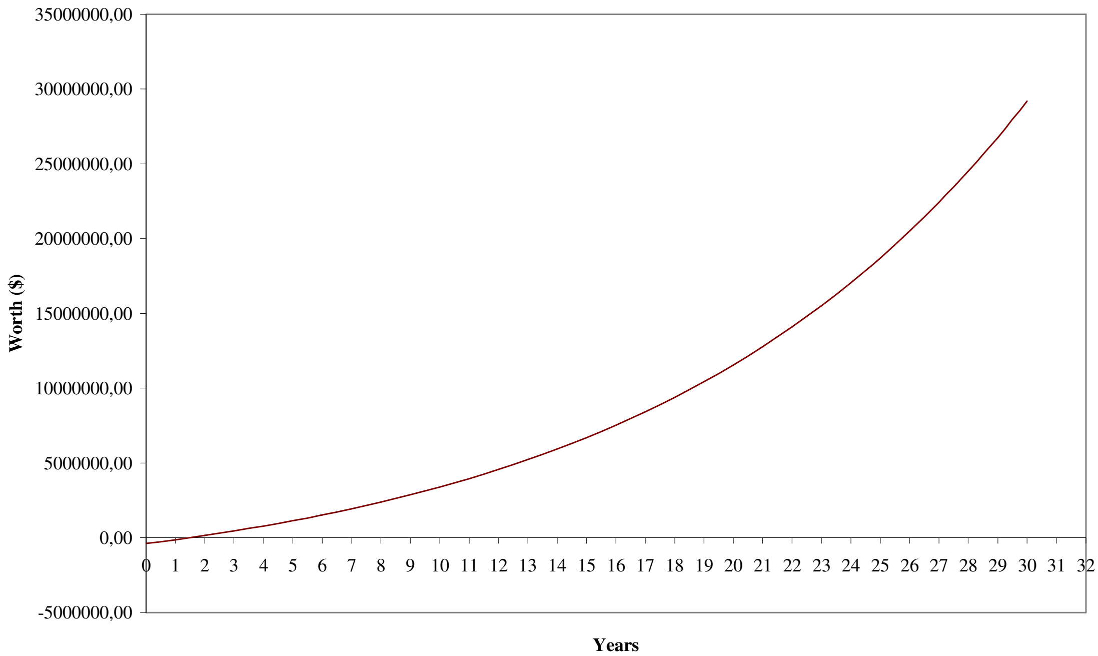


Figure 5.16. Worth of investment in case of pricing on kWh basis for an absorption chiller of 2,288 MW for cooling loads found by averaging, whole year operation.

To find the effect of geothermal fluid price on the project, the investment worths at the end of five years have been determined and given in Table 5.28.

Table 5.28. Investment Worth at the end of five years in case of pricing on kWh basis depending on the geothermal fluid price for an absorption chiller of 2,288 MW for cooling loads found by averaging, whole year operation.

Geothermal Water Price ($/kWh)	Investment Worth ($)	Pay Back Year
0	2.278.242	1
0,0025	1.995.590	1
0,005	1.712.937	2
0,0075	1.430.284	2
0,01	1.147.631	2
0,0125	864.978	2
0,015	582.325	3
0,0175	299.673	4
0,02	17.020	5

Also in Figure 5.17, the graph has been shown to represent the trend of investment worth depending on the changes in the geothermal fluid price.

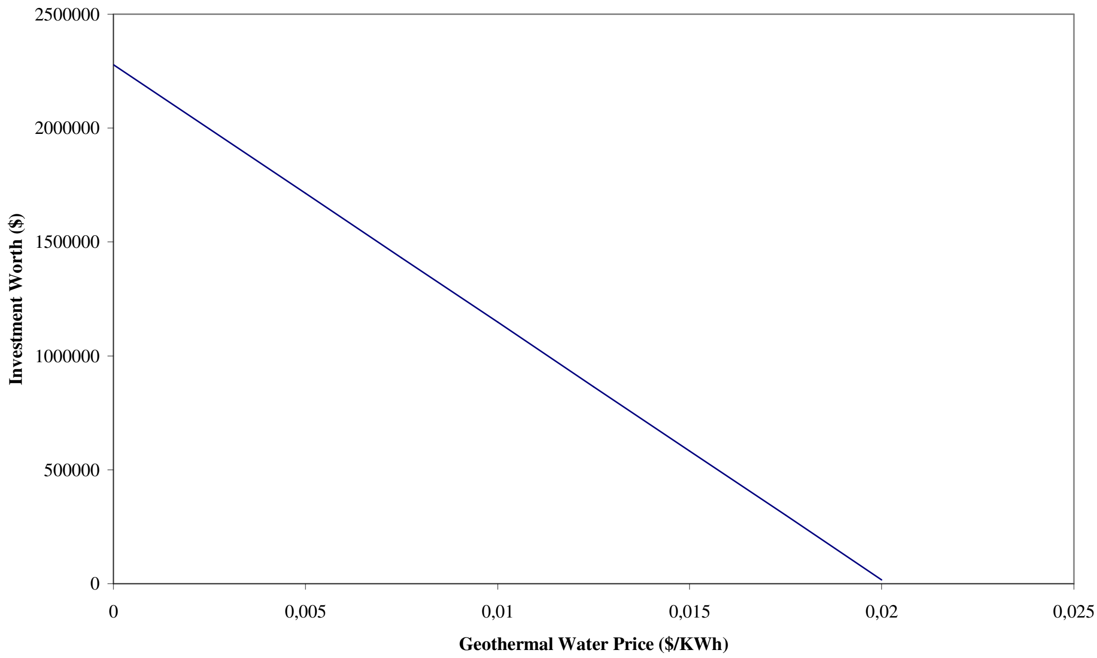


Figure 5.17. The investment worth at the end of five years in case of pricing on kWh basis with respect to geothermal fluid price for an absorption chiller of 2,288 MW for cooling loads found by averaging, whole year operation.

5.3.3.1.2. Pricing on m^3 Basis

When the pricing for m^3 basis have been used for the calculations, the annual cost for the absorption cooling system appears to be \$1.290.689. This value is more than the annual cost of the existing system, which is \$925.068. The worth of investment for several years can be seen in Table 5.29.

Table 5.29. Worth of investment in case of pricing on m3 basis for an absorption chiller of 2,288 MW for cooling loads found by averaging, whole year operation.

	Net Income	Worth of Investment
0		-394.046
1	-199.052	-593.099
2	-214.976	-808.075
3	-232.175	-1.040.251
4	-250.749	-1.291.000
5	-270.809	-1.561.809
6	-292.473	-1.854.283

From the results, it can be seen that the net annual income is negative. That's because the annual cost of the absorption system exceeds the cost of the existing system. Also there are no capital costs for the existing system, which makes the investment cost also negative, and as a result the project cannot pay itself back. So, instead of choosing this alternative, maintaining the existing system is more economical. The behavior of the cash flow is given in Figure 5.18.

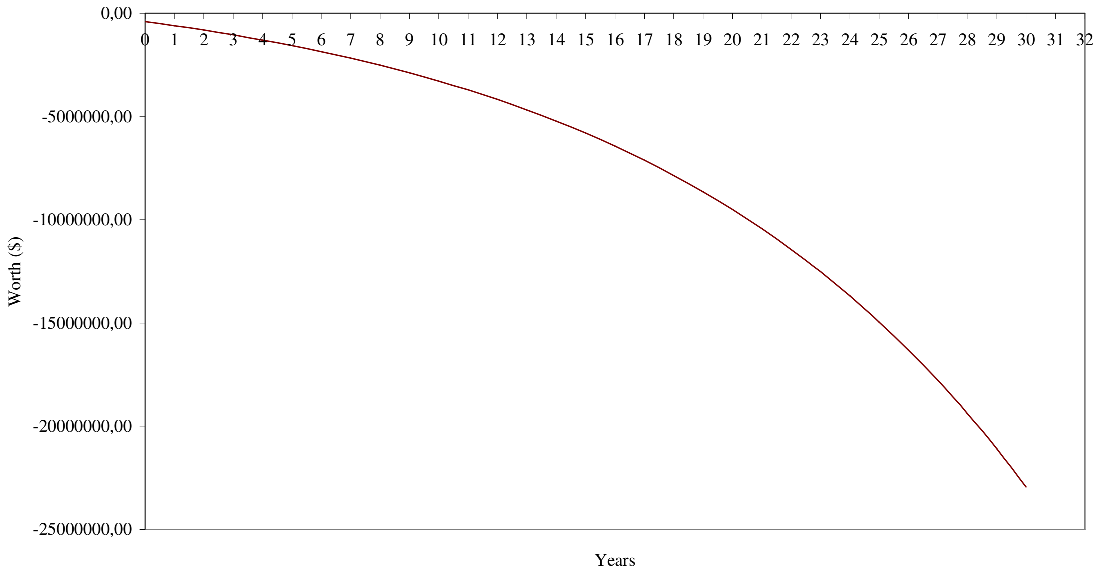


Figure 5.18. Worth of investment in case of pricing on m3 basis for an absorption chiller of 2,288 MW for cooling loads found by averaging, whole year operation.

To find the maximum geothermal fluid price that could make this project feasible, the investment worths at the end of five years have been determined and given in Table 5.30.

Table 5.30. Investment Worth at the end of five years in case of pricing on m3 basis depending on the geothermal fluid price for an absorption chiller of 2,288 MW for cooling loads found by averaging, whole year operation.

Geothermal Water Price ($/m^3)	Investment Worth ($)	Pay Back Year
0	2.278.243	1
0,1	1.604.313	2
0,2	930.383	2
0,3	256.453	4
0,4	-417.476	-
0,5	-1.091.406	-
0,6	-1.765.336	-
0,7	-2.439.266	-
0,8	-3.113.196	-

Also in Figure 5.19, the graph has been shown to represent the trend of investment worth depending on the changes in the geothermal fluid price.

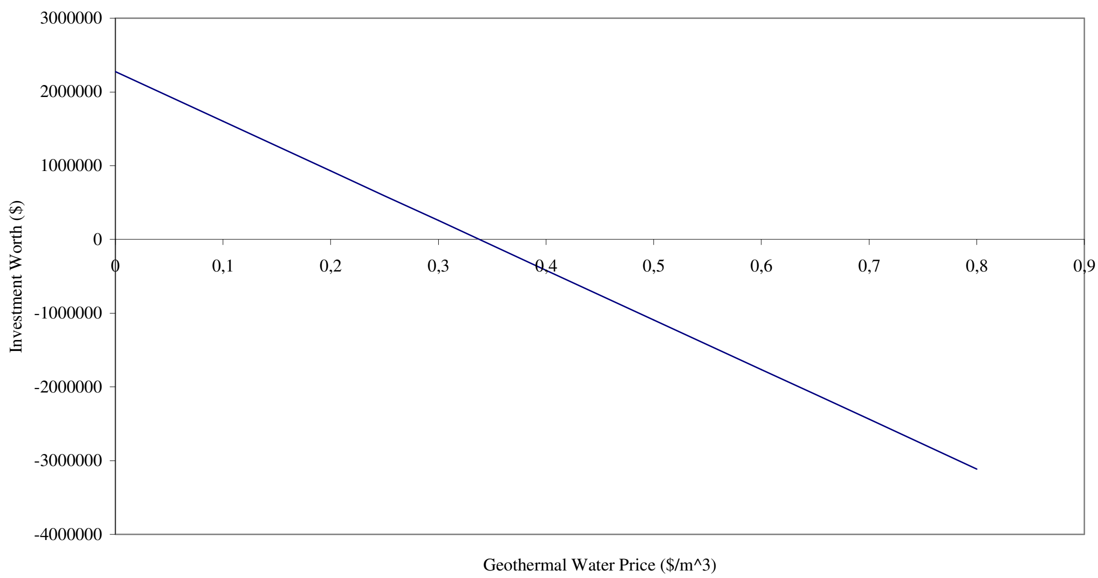


Figure 5.19. The investment worth at the end of five years in case of m3 pricing with respect to geothermal fluid price for an absorption chiller of 2,288 MW for cooling loads found by averaging.

5.4. An Absorption Chiller of 1,496 MW When Whole Year Operation is Considered

The chosen device for this capacity is THERMAX LT-34S. Basic specifications are given in Table 5.31.

Table 5.31. Basic specifications of THERMAX LT-34S

Cooling Capacity (MW)	1,496
Water Inlet Temperature (^oC)	110
Water Exit Temperature (^oC)	95
Water Flow Rate (m^3/h)	128
COP	0,7
Capital Cost ($)	263.878

Throughout the analysis of this machine, it is assumed that the machine works for the whole year at 1,496 MW. Also, since the cooling loads found by regression appears to be invalid in physical sense, only the loads found by averaging will be considered.

5.4.1. Determining the Costs Incurred by the Compression Chillers due to Peaking

The total cooling load for the hospital is 30.849.155 kWh. An absorption chiller with a capacity of 1,496 MW can supply an annual load of 13.104.960 kWh. So the compression chillers should supply a cooling load of 17.744.195 kWh throughout the year. This cooling load leads to an electricity comsumption of 4.436.048 kWh. To find the annual cost of the compression chillers, this value is multiplied by the unit price of the electricity. The result is found as 515.364$.

5.4.2. Determining the Costs Incurred by the Absorption Chiller

The examined machine has a capital cost of approximately \$263.877. The variable costs are calculated for kWh basis and m^3 basis.

5.4.2.1. Cooling Loads Found by Averaging

During the calculations done under this topic, the cooling loads that are going to be used are found by averaging the electricity consumption values for every month.

5.4.2.1.1. Pricing on kWh Basis

To find the annual geothermal fluid cost of absorption cooling machine, the annual cooling supplied by the machine, which is 13.104.960 kWh, is multiplied by the unit price of geothermal fluid in case of kWh pricing. For maintenance cost, since those costs are given for 2160 working hours, they are modified for 8760 working hours, by multiplying them with the ratio of the working hours, which is nearly 4. The results are given in Table 5.32.

Table 5.32. Total annual cost of the absorption system in case of pricing on kWh basis for an absorption chiller of 1,496 MW for cooling loads found by averaging, whole year operation.

Electricity	8.854
Water Loss (Vaporization)	48.960
Chemicals	6.296
Maintenance	3.778
Per Machine (\$)	67.888

Total Operational (\$)	67.888
Geothermal Water (\$)	132.127
Peaking Cost (\$)	515.364

Annual Cost (\$)	715.380

5.4.2.1.2. Pricing on m^3 Basis

When pricing is based on m^3 basis, the only difference is that the annual cost is found by using the annual geothermal fluid consumption value of the absorption cooling machine. The results are given in Table 5.33.

Table 5.33. Total annual cost of the absorption system in case of pricing on m3 basis for an absorption chiller of 1,496 MW for cooling loads found by averaging,whole year operation.

Electricity	14.044
Water Loss (Vaporization)	48.960
Chemicals	6.296
Maintenance	3.778
Per Machine ($)	73.078

Total Operational ($)	73.078
Geothermal Water ($)	364.484
Peaking Cost ($)	515.364

Annual Cost ($)	952.927

5.4.3. Comparing Absorption Cooling System with the Existing Cooling System

The procedure used for comparing this machine with the compression cooling system is the same as the first machine except that the loads found by regression won't be used in the calculations.

5.4.3.1. Cooling Loads by Averaging

Throughout this headline, the calculations will be done by using the cooling loads found by averaging.

5.4.3.1.1. Pricing on kWh Basis

When the pricing for kWh basis have been used for the calculations, the annual cost for the absorption cooling system appears to be \$715.380. This value is lower than the annual cost of the existing system, which is \$925.068. The worth of investment for several years can be seen in Table 5.34.

Table 5.34. Worth of investment in case of pricing on kWh basis for an absorption chiller of 1,496 MW for cooling loads found by averaging, whole year operation.

	Net Income	Worth of Investment
0		-263.877
1	188.578	-75.299
2	203.664	128.365
3	219.957	348.323
4	237.554	585.877
5	256.558	842.436
6	277.083	1.119.520
7	299.250	1.418.770
8	323.190	1.741.960
9	349.045	2.091.006
10	376.969	2.467.975

The net annual income is positive in this case. So this alternative can pay itself back. As a result, the discounted pay back is found to be two years. The behavior of the cash flow is given in Figure 5.20.

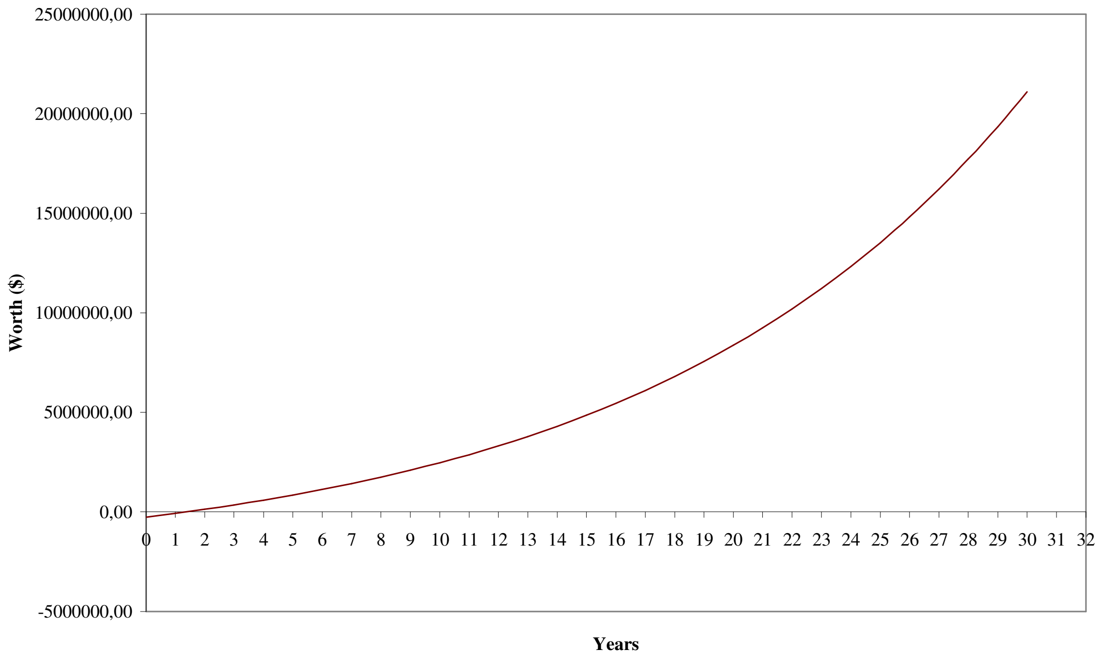


Figure 5.20. Worth of investment in case of pricing on kWh basis for an absorption chiller of 1,496 MW for cooling loads found by averaging, whole year operation.

To find the effect of geothermal fluid price on the project, the investment worths at the end of five years have been determined and given in Table 5.35.

Table 5.35. Investment Worth at the end of five years in case of pricing on kWh basis depending on the geothermal fluid price for an absorption chiller of 1,496 MW for cooling loads found by averaging, whole year operation.

Geothermal Water Price ($/kWh)	Investment Worth ($)	Pay Back Year
0	1.617.574	1
0,0025	1.425.370	1
0,005	1.233.166	2
0,0075	1.040.962	2
0,01	848.758	2
0,0125	656.555	2
0,015	464.351	3
0,0175	272.147	3
0,02	79.943	4

Also in Figure 5.21, the graph has been shown to represent the trend of investment worth depending on the changes in the geothermal fluid price.

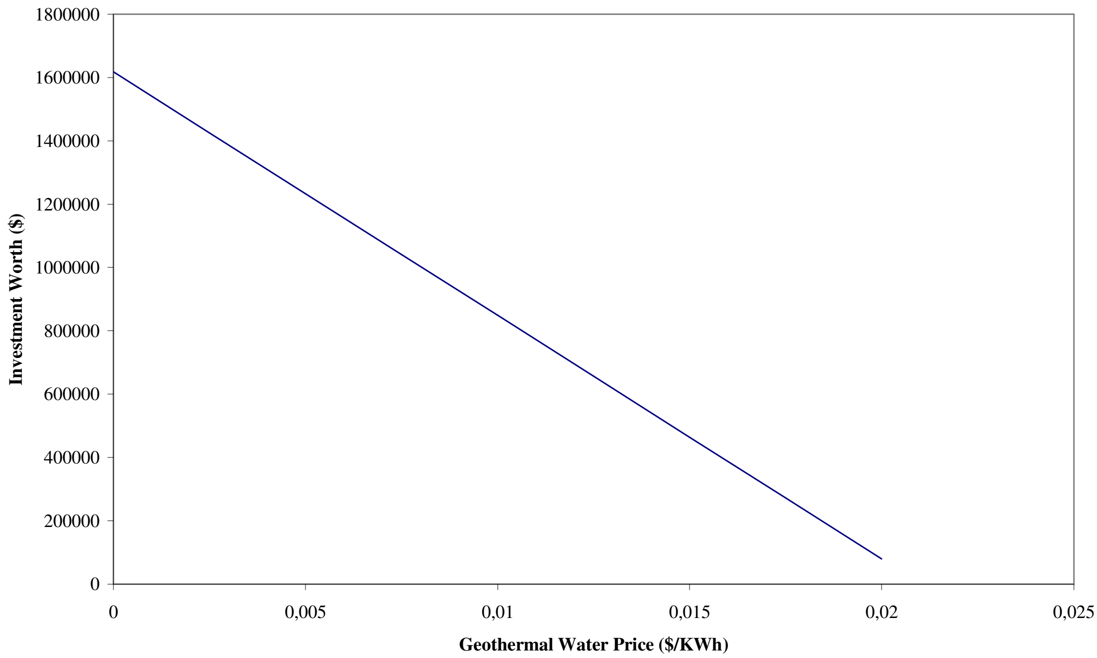


Figure 5.21. The investment worth at the end of five years in case of pricing on kWh basis with respect to geothermal fluid price for an absorption chiller of 1,496 MW for cooling loads found by averaging, whole year operation.

5.4.3.1.2. Pricing on m^3 Basis

When the pricing for m^3 basis have been used for the calculations, the annual cost for the absorption cooling system appears to be $1.151.018. This value is larger than the annual cost of the existing system, which is $925.068. The worth of investment for several years can be seen in Table 5.36.

Table 5.36. Worth of investment in case of pricing on m3 basis for an absorption chiller of 1,496 MW for cooling loads found by averaging, whole year operation

	Net Income	Worth of Investment
0		-263.877
1	-48.968	-312.846
2	-52.886	-365.732
3	-57.116	-422.849
4	-61.686	-484.535
5	-66.621	-551.156
6	-71.950	-623.107

From the results, it can be seen that the net annual income is negative. That's because the annual cost of the absorption system exceeds the cost of the existing system. Also there are no capital costs for the existing system, which makes the investment cost also negative, and as a result the project cannot pay itself back. So, instead of choosing this alternative, maintaining the existing system is more economical. The behavior of the cash flow is given in Figure 5.22.

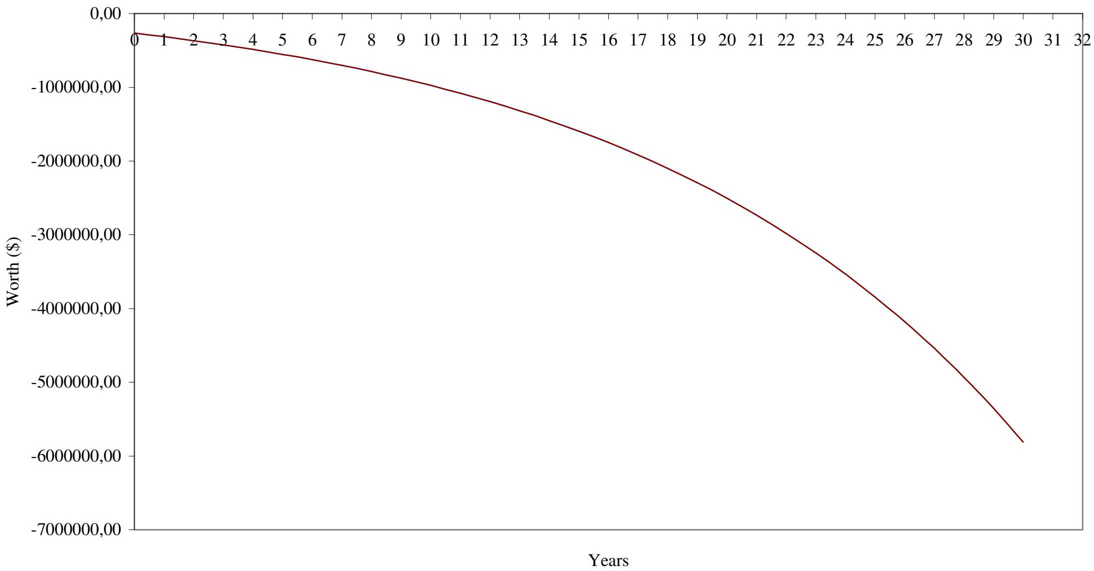


Figure 5.22. Worth of investment in case of pricing on m3 basis for an absorption chiller of 1,496 MW for cooling loads found by averaging, whole year operation.

To find the maximum geothermal fluid price that could make this project feasible, the investment worths at the end of five years have been determined and given in Table 5.37.

Table 5.37. Investment Worth at the end of five years in case of pricing on m3 basis depending on the geothermal fluid price for an absorption chiller of 1,496 MW for cooling loads found by averaging, whole year operation.

Geothermal Water Price ($/m^3)	Investment Worth ($)	Pay Back Year
0	1.587.125	1
0,1	1.211.856	2
0,2	836.587	2
0,3	461.318	3
0,4	86.050	4
0,5	-289.219	-
0,6	-664.488	-
0,7	-1.039.757	-
0,8	-1.415.026	-

Also in Figure 5.23, the graph has been shown to represent the trend of investment worth depending on the changes in the geothermal fluid price.

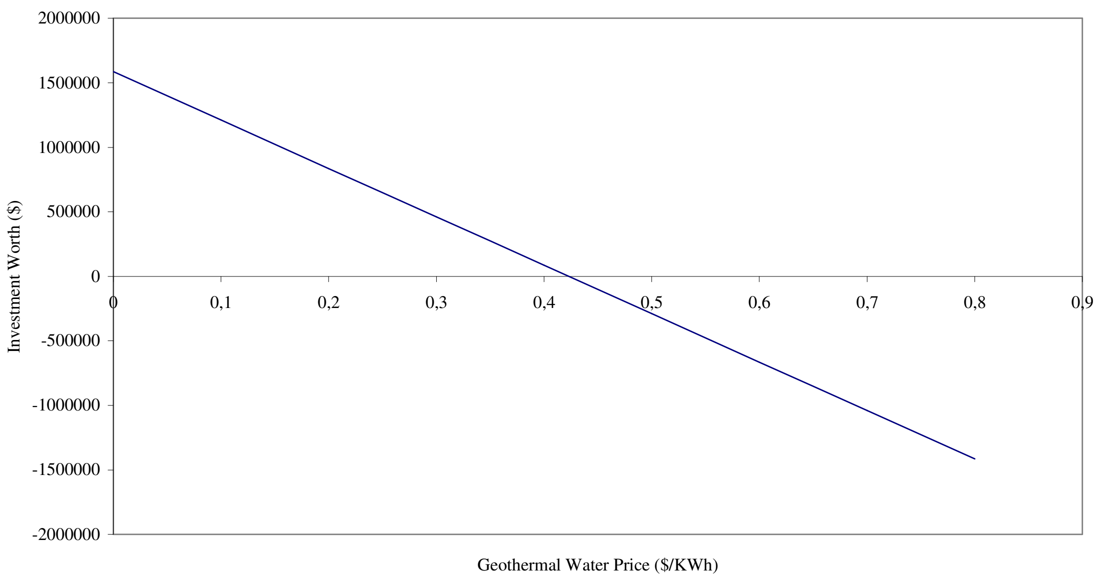


Figure 5.23. The investment worth at the end of five years in case of m3 pricing with respect to geothermal fluid price for an absorption chiller of 1,496 MW for cooling loads found by averaging.

CHAPTER 6

RESULTS AND DISCUSSION

In this study, implementation of an absorption cooling system into a hospital, which uses geothermal energy as the primary energy source has been examined. The case study chosen for this aim was Dokuz Eylül University Research and Application Hospital, which has a cooling load throughout the year. The annual cost of cooling of the hospital with compression chillers is found to be $925.068 for cooling loads obtained by averaging and $1.749.428 for cooling loads obtained by regression.

Normally, the absorption cooling projects has been applied, when there is a waste process heat, or when there is a natural gas resource available for use. However, in this case the main energy source is geothermal water.

During the study, three different absorption cooling machines with different capacities have been examined. The break-even geothermal prices have been found for each machine by considering an absorption cooling project as feasible, when the discounted pay back period is below or equal to five years. The results are determined for two pricing options, kWh pricing and m^3 pricing.

Also at the beginning of the project, it was intended to find the monthly electricity consumption values with two methods. The first method was averaging and the second one was linear regression. When the linear regression method was applied and the annual cost of cooling of the hospital with compression chillers have been found, it appears to be $1.749.428, which is nearly two times the value found by averaging. So, linear regression method was used only for the first alternative for illustration of the effect of increasing cooling loads in the hospital.

The first machine chosen was a device with a capacity of 4,818 MW. This capacity can provide nearly 37% of the hospital's total capacity when compared with the total capacity of the hospital, which is 13,05 MW. As a result, it had been seen that the annual cost of operating this machine, exceeds the annual cost incurred by the existing compression chillers for m^3 pricing option. When cooling loads obtained by averaging are used, difference between annual costs is $575.000. The difference becomes $1.250.000 when cooling loads obtained by regression are used.

To make the project feasible for m^3 pricing, the geothermal fluid price should at least be lowered to 0,13 $\$/m^3$ for averaging method and 0,17 $\$/m^3$ for regression method. These prices are quite low compared to the existing price of the geothermal fluid, which is 0,5698 $\$/m^3$.

When the kWh pricing option is considered, the averaging method gives a pay back period of 13 years. Although the project seems to pay itself, since the period is too long, it is considered as uneconomical. To make this alternative economical, the geothermal fluid price should at least be lowered to 0,0075 \$/kWh. The calculated kWh price of the geothermal fluid should be lowered at least 25% to reach this value.

The only option that makes this project feasible is the kWh pricing option when the cooling loads obtained by regression method are used. This alternative gives a pay back period of five years. The calculated kWh price of the geothermal fluid seems to be appropriate for this project to be feasible.

When regression method is compared with the averaging method, the main difference is the increase in cooling load. This increase effects the results considerably because as the cooling load increases, the cooling capacity does not change. Since the results appear to be more feasible for regression method, it can be concluded that increasing cooling load without increasing the cooling capacity favors an absorption cooling machine with respect to a compression cooling machine. On the other hand, increasing cooling load without increasing cooling capacity leads to higher load factors. With regression method, the load factor is higher than 50% for the existing system, which is unlikely to occur for a compression system that has been implemented to supply a peak cooling demand.

The second machine chosen was a device with a capacity of 2,288 MW. This capacity can provide nearly 17,5% of the hospital's total capacity when compared with the total capacity of the hospital, which is 13,05 MW. As a result, it had been seen that the annual cost of operating this machine, exceeds the annual cost incurred by the existing compression chillers for m^3 pricing. For kWh pricing on the other hand, the discounted pay back period appears to be four years.

To make the 2,288 MW machine feasible for m^3 pricing, the geothermal fluid price should be around 0,275 $\$/m^3$, which is again considerably lower than the existing geothermal fluid price, which is 0,5698 $\$/m^3$. On the other hand, when the kWh pricing is considered it is even possible to implement this absorption cooling system when the geothermal fluid price is 0,0115 $/kWh. This value is greater than the existing geothermal fluid price of 0,01008 $/kWh.

When a whole year operation is considered for the Thermax LT-52S, the results considerably change. For kWh pricing, the annual costs lowered in this situation. This is because of the fact that the unit cooling cost of absorption cooling system is lower than the compression cooling system for kWh pricing. So, the pay back period becomes two years, and the break-even geothermal price increases to 0,02 $/kWh, which is nearly two times the existing price.

On the other hand, the unit cost of absorption cooling system is higher than the compression cooling system for m^3 pricing. So whole year operation effects the m^3 pricing option exactly on the opposite way in terms of annual costs. The break-even geothermal fluid price is 0,34 $/m^3$ for this case. The existing fluid price is 68% higher than this break-even fluid price.

The third machine chosen was a device with a capacity of 1,496 MW. This capacity can provide nearly 11,5% of the hospital's total capacity when compared with the total capacity of the hospital, which is 13,05 MW. When conducting the calculations for this machine only whole year operation is considered. It shows nearly the same trend as Thermax LT-52S with whole year operation. For kWh pricing, the annual costs are lowered. This is because of the fact that the unit cooling cost of absorption cooling system is lower than the compression cooling system for kWh pricing. So, the pay back period becomes two years, and the break-even geothermal price increases to 0,021 $/kWh, which is two times the existing price.

On the other hand, the unit cost of absorption cooling system is higher than the compression cooling system for m^3 pricing. So whole year operation again effects the m^3 pricing option exactly on the opposite way in terms of annual costs. The break-even geothermal fluid price is 0,42 $/m^3$ for this case. The existing fluid price is 35% higher than this break-even fluid price.

The results found by using the existing geothermal fluid prices for the selected three machines are summarized in Table 6.1.

Table 6.1. Summary of the results for the selected absorption cooling machines

<table>
<tr><td colspan="2"></td><td></td><td></td><td colspan="2">Whole Year Operation</td></tr>
<tr><td colspan="2"></td><td>York YIA-HW-14F3</td><td>Thermax LT-52S</td><td>Thermax LT-52S</td><td>Thermax LT-34S</td></tr>
<tr><td colspan="2">Capacity (MW)</td><td>4,818</td><td>2,288</td><td>2,288</td><td>1,496</td></tr>
<tr><td colspan="2">Specific Fluid Consumption (m^3 / kWh)</td><td>0,0831</td><td>0,0776</td><td>0,0776</td><td>0,0783</td></tr>
<tr><td colspan="2">Percentage of Total Capacity (%)</td><td>37</td><td>17,5</td><td>17,5</td><td>11,5</td></tr>
<tr><td colspan="2">Capital Cost ($)</td><td>700.000</td><td>394.046</td><td>394.046</td><td>263.878</td></tr>
<tr><td colspan="2">Annual Cost for Compression Chillers Found by Averaging Method ($)</td><td colspan="4">925.068</td></tr>
<tr><td rowspan="2">Annual Cost of Absorption Chillers</td><td>For kWh pricing ($/kWh)</td><td>836.259</td><td>796.011</td><td>632.340</td><td>715.380</td></tr>
<tr><td>For m^3 pricing ($/$m^3$)</td><td>1.507.389</td><td>1.059.091</td><td>1.092.597</td><td>952.927</td></tr>
<tr><td rowspan="2">Geothermal Water Price</td><td>For kWh pricing ($/kWh)</td><td colspan="4">0,01008</td></tr>
<tr><td>For m^3 pricing ($/$m^3$)</td><td colspan="4">0,5698</td></tr>
<tr><td rowspan="2">Break-Even Geothermal Water Price</td><td>For kWh pricing ($/kWh)</td><td>0,0075</td><td>0,0115</td><td>0,02</td><td>0,021</td></tr>
<tr><td>For m^3 pricing ($/$m^3$)</td><td>0,13</td><td>0,275</td><td>0,34</td><td>0,42</td></tr>
</table>

In Table 6.2, the unit cost values of both absorption cooling and compression cooling as well as the average cooling cost is given for each alternative.

Table 6.2. Unit cost of absorption and compression cooling systems

				Whole Year Operation	
		York YIA-HW-14F3	Thermax LT-52S	Thermax LT-52S	Thermax LT-34S
Capacity (MW)		4,818	2,288	2,288	1,496
Unit Cost of Compression Chillers ($)		0,02904			
Unit Cost of Absorption Chillers	For kWh pricing ($/kWh)	0,02567	0,0198	0,01536	0,01526
	For m^3 pricing ($/kWh)	0,05897	0,04086	0,03925	0,03339
Overall Unit Cost of Cooling	For kWh pricing ($/kWh)	0,02711	0,0258	0,02049	0,023189
	For m^3 pricing ($/kWh)	0,04886	0,03433	0,03542	0,03089

In Table 6.3, the investment worth values at the end of five years and the pay back period when the geothermal fluid price decreased to 0,005 $/kWh has been given.

Table 6.3. The Investment worth at the end of five years and the pay back period when the geothermal fluid price has been decreased to 0,005 $/kWh

			Whole Year Operation	
	York YIA-HW-14F3	Thermax LT-52S	Thermax LT-52S	Thermax LT-34S
Investment Worth at the End of Five Years	430.641	691.190	1.712.937	1.233.166
Pay Back Period	4	3	2	2

Also in Table 6.4, the investment worth values at the end of fifth year and the pay back period when the geothermal fluid price decreased to 0,1 $/m^3 has been given.

Table 6.4. The Investment worth at the end of five years and the pay back period when the geothermal fluid price has been decreased to 0,1 $/m3

			Whole Year Operation	
	York YIA-HW-14F3	Thermax LT-52S	Thermax LT-52S	Thermax LT-34S
Investment Worth at the End of Five Years	284.472	797.821	1.604.313	1.211.856
Pay Back Period	4	2	2	2

CHAPTER 7

CONCLUSIONS

Absorption cooling systems are alternatives to fossil-fuel and electricity based conventional cooling systems. The main difference is that they require thermal energy (steam or hot water) as the primary energy need. Also, the electricity needs for the absorption chillers are much less than the conventional chillers, which make them economically competitive.

The systems considered in this study are single-effect indirect-fired systems, which are available to use at low water temperatures. When considering the use of these machines in cooling projects, generally the main aspect is that the hot water used in the system is rejected water from a process. However, in the case of Dokuz Eylül University Research and Application Hospital cooling, the hot water used is geothermal fluid, which has a certain cost. So, the calculations are usually based on the comparison of the geothermal fluid cost of the absorption cooling systems and the electricity costs of the conventional compression cooling systems.

As a result of the calculations on this study, for kWh pricing, it is seen that among the three alternatives, the best one is to implement an absorption chiller with a capacity of 2,288 MW into the hospital under the existing circumstances if the machine is assumed to work throughout the year. The capital invested for this alternative is \$394.046 and the annual cost is \$632.340, which is 31% lower than the existing annual cost incurred for cooling. The discounted pay back period of this alternative is two years, which is very favorable for a long term project.

When m^3 pricing is considered, the best alternative seems to be the machine with a capacity of 1,496 MW. The annual cost of the machine is \$952.927, which is 3% higher than the existing annual cost incurred for cooling. This machine shows a negative annual income due to its high geothermal fluid consumption. Since the capital cost is also negative, there appears to be no payback period, and this machine becomes inappropriate to implement into the hospital.

When the capacities of the absorption chillers are examined with respect to the costs incurred with them based on m^3 pricing and kWh pricing with an operation with a load factor, it is seen that with increasing capacity the costs increased. This is due to the fact that the unit cost of cooling the hospital with the compression chillers is lower than cooling with absorption chillers.

On the other hand, when the changes in the costs of these alternatives are examined for whole year operation with respect to the change in the geothermal fluid price based on kWh pricing, the best results are achieved with a capacity of 2,288 MW. This is because the specific geothermal fluid consumption of this machine is less than the other two machines. The required geothermal fluid price based on kWh of water is 0,02 \$/kWh for whole year operation. This value is nearly two times the existing geothermal fluid price.

When the break-even geothermal fluid prices are examined, the situation depends more strongly on the specific fluid consumption rate. Since the specific fluid consumption of the 4,818 MW machine is much higher than the other machines, it seems to need higher decreases in fluid price. For m^3 pricing, the fluid price should be lowered to 0,13 \$/m^3,which nearly 23% of the existing geothermal fluid price. Even for kWh pricing, the fluid price should be lowered to 75% of its existing value.

When the absorption cooling machine with 2,288 MW capacity is examined, the results appear to be much better than the 4,818 MW machine. For an operation with a load factor, break-even geothermal price is 0,0115 \$/kWh for kWh pricing, which is higher than the existing price. For whole year operation, the break-even geothermal price is 0,02 \$/kWh which is nearly two times the existing price. The reason is that the situation becomes better for whole year operation than an operation with a load factor is that the unit price of absorption cooling is lower than the compression cooling for kWh pricing option.

For m^3 pricing, break-even geothermal fluid price is 0,275 \$/m^3 for 2,288MW machine for an operation with a load factor, which is nearly half of the existing price. For whole year operation, it becomes 0,34 \$/m^3.

When the absorption cooling machine with a capacity of 1,496 MW is examined for kWh pricing, the break-even geothermal fluid price is 0,021 \$/kWh, which is two times the existing price. Although this value is slightly higher than the corresponding value for 2,288 MW machine, 2,288 MW machine shows higher gains for upcoming years after the fifth year. Also as the fluid price decreases, the gains increase more with respect to the 1,496 MW machine. The break-even geothermal fluid price is 0,42 \$/m^3 for m^3 pricing, which is nearly 25% lower than the existing fluid price. This value is higher than the corresponding value for 2,288 MW machine. This is because of the fact that the unit cost of absorption cooling is actually higher than the unit cost of compression cooling and the 2,288 MW machine consumes more fluid than the 1,496 MW machine.

Based on the kWh pricing applied, it is possible to implement absorption cooling systems with capacities of 2,288 MW and 1,496 MW. Based on the m^3 pricing applied, it seems to be possible to implement a 1,496 MW absorption cooling machine, if the fluid price has been dropped to 0,42 $/$m^3$. Also, it is possible to implement a 2,288 MW absorption cooling machine with whole year operation assumption, if the fluid price has been dropped to 0,34 $/$m^3$. Since 1,496 MW absorption cooling machine has a higher break-even geothermal fluid price, 1,496 MW capacity absorption cooling machine seems to be the best option for m^3 pricing.

Although kWh pricing options give economical results, m^3 pricing shows higher annual costs even with the best option chosen for the hospital, which includes the implementation of a 1,496 MW machine with a whole year operation. Since the pricing system applied on the geothermal fluid depends on the m^3 pricing right now, those prices that have been found by using m^3 pricing option should be used to determine the economic feasibility of implementing an absorption cooling machine. So, as a result of this study, it is seen that implementing an absorption cooling system into Dokuz Eylül University Research and Application Hospital is not economical under the present circumstances.

If the results were indicated an economical project, the results should also be considered in terms of sustainability of the reservoir. Normally the pressure and the fluid level of the reservoir in Balçova are decreasing during the heating period and then increasing during summer since the reservoir is not used considerably (Aksoy 2003). If an absorption cooling system has been implemented into the hospital, since the cooling capacity reaches its maximum during summer, the geothermal fluid consumption would also be at its maximum. For the smallest machine considered in this study, the maximum geothermal fluid consumption would be more than 100 m^3. This amount of fluid extraction during summer may yield to a dropdown in the fluid level and pressure of the production wells.

As a result of this study, for a medium temperature geothermal reservoir, implementing an absorption cooling system into a space, which is cooled considerably throughout the year, can be economical when the geothermal fluid price is around 0,35-0,45 $/$m^3$. Also, although the existing situation suggests that the increasing capacity in absorption chillers increases the overall costs of implementing absorption cooling systems, decreasing geothermal fluid prices far below break-even prices may reverse the situation. So with low fluid prices, increasing absorption chiller capacity can make absorption cooling systems more economical.

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APPENDIX A

DATA FOR THE EXISTING COOLING SYSTEM

Table A.1. Existing electricity consumption values found by averaging

KWh	2000	2001	2002	2003	Averages	Use for Cooling
January	1000440	1195215	1192695	1224090	1153110	373724
February	1216950	1015035	994035	1051155	1069294	289907
March	1092630	1201620	1068890	1179045	1135546	356160
April	1103970	771330	1151535	1131795	1039658	260271
May	1036350	1007685	1121715	1413510	1144815	365429
June	1336320	1110480	1312080	1631595	1347619	568232
July	1727145	1843695	3045000	2285430	2225318	1445931
August	2149350	2061885	2483985	2382345	2269391	1490005
September	2000775	2163630	1776390	1988490	1982321	1202935
October	1613430	1656165	1221045		1496880	717494
November	1085175	1208655	1217370		1170400	391014
December	958755	1065750	1067220		1030575	251189

Average Use	2269391
Minimum Use	1030575
Minimum Use for Cooling	251189
Maximum Use for Cooling	1490005

	MWh	KWh
Total Use	7712,29	7712288,831
Total Cooling	30849,2	30849155,32

Table A.2. Existing electricity consumption values found by regression

KWh	2000	2001	2002	2003	2004	Forecasted 2005	Use for Cooling
January	1E+06	1195215	1192695	1224090	1263150	1341406,50	928852
February	1E+06	1015035	994035	1051155		887859,00	475304
March	1E+06	1201620	1068890	1179045	1286880	1275590,50	863036
April	1E+06	771330	1151535	1131795	1255380	1281787,50	869233
May	1E+06	1007685	1121715	1413510	1237320	1405645,50	993091
June	1E+06	1110480	1312080	1631595	1512945	1642993,50	1230439
July	2E+06	1843695	3045000	2285430		3231973,50	2819419
August	2E+06	2061885	2483985	2382345		2661771,00	2249216
September	2E+06	2163630	1776390	1988490		1833888,00	1421333
October	2E+06	1656165	1221045		1621200	1486113,00	1073558
November	1E+06	1208655	1217370		1159200	1207341,00	794786
December	958755	1065750	1067220			1247505,00	834950

Average Use	3231973,50
Minimum Use	887859,0001
Minimum Use for Cooling	475304,3225
Maximum Use for Cooling	2819418,822

	MWh	KWh
Total Use	14553,218	14553217,87
Total Cooling	58212,871	58212871,48

Table A.3. Annual cost of operating the exisitng compression cooling system found by averaging

Installed Capacity for Cooling (MW)	13,05	Cost of Electricity	0,158
Minimum Capacity Used for Cooling (MW)	2,2	Dollar Exchange	1,36
COP of Absorption Chiller	0,663179628	Cost of Geothermal Water	0,01008
COP of Compression Chiller	4	Monthly Interest Rate	0,00667

Total Annual Cost Including Interest (YTL)	1258093,017	Total Annual Cost (Dollar)	925068

Total Capacity	13,05 MW
Total Working Hours for Full Capacity	2363,919948

Table A.4. Annual cost of operating the exisitng compression cooling system found by regression

Installed Capacity for Cooling (MW)	13,05	Cost of Electricity	0,158	YTL/KWh
Minimum Capacity Used for Cooling (MW)	2,2	Dollar Exchange	1,36	YTL
COP of Absorption Chiller	0,66317963	Cost of Geothermal Water	0,010082	$/KWh
COP of Compression Chiller	4	Monthly Interest Rate	0,006667	

Total Annual Cost Including Interest (YTL)	2379222,813	Total Annual Cost (Dollar)	1749428

Total Capacity	13,05 MW
Total Working Hours for Full Capacity	4460,756435

Table A.5. Monthly geothermal water use for heating

	2002	2003	Average
January	57211	84313	70762
February	55064	81230	68147
March	79229	55305	67267
April	70476	25731	48103,5
May	0	0	0
June	0	0	0
July	0	0	0
August	0	0	0
September	0	0	0
October	0	0	0
November	37138	45024	41081
December	55537	49043	52290
Total	354655	340646	347651

Table A.6. Comparison of capacities used for cooling found by using weather data and electricity data

	When Weather Data Used	When Electricity Data Used	When Electricity Data Used
	Monthly Average (MW)	Monthly Average (MW)	Regression (MW)
January	2,20	3,27	4,30
February	2,96	2,54	2,20
March	4,48	3,12	3,99
April	6,66	2,28	4,02
May	9,28	3,20	4,60
June	11,62	4,98	5,70
July	13,05	12,66	13,05
August	12,71	13,05	10,41
September	10,43	10,54	6,58
October	7,76	6,28	4,97
November	5,26	3,42	3,68
December	3,16	2,20	3,86

APPENDIX B

DATA EXTRACTED FOR THE ABSORPTION COOLING SYSTEMS BY AVERAGING THE COOLING LOADS AND PER kWh PRICING

Table B.1. Required monthly compression chiller capacities when a 4,818 MW absorption chiller is used

Capacity (MW)	Electricity Consumption for Cooling(kWh)
13,05	1490004,798
2,2	251188,5484

Linear Regression for Capacity and Electricity Consumption

Intercept	0
Slope	8,75836E-06

	Electricity Consumption for Cooling (kWh)	Corresponding Cooling Load (kWh)	Required Maximum Capacities (MW)	Capacity of Absorption Cooling (MW)	Required Compression Chiller Capacity (MW)
January	373724	1494894	3,27	4,818	0
February	289907	1159629	2,54	4,818	0
March	356160	1424639	3,12	4,818	0
April	260271	1041084	2,28	4,818	0
May	365429	1461714	3,20	4,818	0
June	568232	2272929	4,98	4,818	0,158783633
July	1445931	5783724	12,66	4,818	7,845986184
August	1490005	5960019	13,05	4,818	8,232
September	1202935	4811739	10,54	4,818	5,717737292
October	717494	2869974	6,28	4,818	1,466067552
November	391014	1564054	3,42	4,818	0
December	251189	1004754	2,20	4,818	0

Table B.2. Annual costs incurred by the compression chillers when a 4,818 MW absorption chiller is used

Maximum Usage Corresponds to the Maximum Capacity

13,05	1490004,798
4,818	550102,921

For the months, which have electricity use above 550102,921 kWh, compression chillers would be used.

	Average Electricity Consumption (kWh)	Consumption for Cooling (kWh)	Electricity Use for Compression Chillers (kWh)	Energy Use for Absorption Chillers (kWh)
January	1153110	373723,5484	0	1494894,194
February	1069293,75	289907,2984	0	1159629,194
March	1135546,25	356159,7984	0	1424639,194
April	1039657,5	260271,0484	0	1041084,194
May	1144815	365428,5484	0	1461714,194
June	1347618,75	568232,2984	18129	2200411,684
July	2225317,5	1445931,048	895828	2200411,684
August	2269391,25	1490004,798	939902	2200411,684
September	1982321,25	1202934,798	652832	2200411,684
October	1496880	717493,5484	167391	2200411,684
November	1170400	391013,5484	0	1564054,194
December	1030575	251188,5484	0	1004754,194

Cooling by Compression Chiller (kWh)	10696327,55
Total Cost Incurred by Compression Chiller (YTL)	433833,2399
Total Cost Incurred by Compression Chiller ($)	318995,0293

Table B.3. Annual costs incurred by the absorption chillers and the total annual costs when a 4,818 MW absorption chiller is used

Annual Electricity Cost of the Existing Cooling System
925068,3952 13,05

One Absorption Cooling Machine with a capacity of 4,818 MW.

Capacity (KW) 4818
Required Water (m^3/h) 400,5 (At 120 C)

Working Hours
4178,94 hours

Operational Costs ($)

Electricity	109322
Water Loss (Vaporization)	75221
Chemicals	9673
Maintenance	5804

Per Machine ($)	200020

Capital Cost ($)	700000

Total Operational ($)	200020
Geothermal Water ($)	317243
Peaking Cost ($)	318995

Total ($)	700000

Annual Cost ($)	836259

Cooling by Absorption Chiller (KWh)	20152827,77
Geothermal Energy Use (KWh)	30388188,83
Geothermal Water Use (m^3)	1673665,623

Total Working Hours for Full Capacity	4178,940382

Table B.4. Investment worth for a 4,818 MW compression chiller

Interest Rate	0,08
Annual Cost (Absorption)	836258,53
Annual Cost (Electricity)	925068,40

	Annual Cost (Absorption)	Annual Cost (Electricity)	Annual Income	Interest	Net Income	Worth of Investment
0						-700000,00
1	836258,53	925068,40	88809,87	-56000,00	32809,87	-667190,13
2	836258,53	925068,40	88809,87	-53375,21	35434,66	-631755,47
3	836258,53	925068,40	88809,87	-50540,44	38269,43	-593486,05
4	836258,53	925068,40	88809,87	-47478,88	41330,98	-552155,06
5	836258,53	925068,40	88809,87	-44172,40	44637,46	-507517,60
6	836258,53	925068,40	88809,87	-40601,41	48208,46	-459309,14
7	836258,53	925068,40	88809,87	-36744,73	52065,14	-407244,00
8	836258,53	925068,40	88809,87	-32579,52	56230,35	-351013,65
9	836258,53	925068,40	88809,87	-28081,09	60728,78	-290284,88
10	836258,53	925068,40	88809,87	-23222,79	65587,08	-224697,80
11	836258,53	925068,40	88809,87	-17975,82	70834,04	-153863,76
12	836258,53	925068,40	88809,87	-12309,10	76500,77	-77362,99
13	836258,53	925068,40	88809,87	-6189,04	82620,83	5257,84
14	836258,53	925068,40	88809,87	420,63	89230,49	94488,33
15	836258,53	925068,40	88809,87	7559,07	96368,93	190857,27
16	836258,53	925068,40	88809,87	15268,58	104078,45	294935,72

Table B.5. Required monthly compression chiller capacities when a 2,288 MW absorption chiller is used

Capacity (MW)	Electricity Consumption for Cooling(kWh)
13,05	1490004,798
2,2	251188,5484

Linear Regression for Capacity and Electricity Consumption

Intercept	0
Slope	8,75836E-06

	Electricity Consumption for Cooling (kWh)	Corresponding Cooling Load (kWh)	Required Maximum Capacities (MW)	Capacity of Absorption Cooling (MW)	Required Compression Chiller Capacity (MW)
January	373724	1494894	3,27	2,288	0,985205772
February	289907	1159629	2,54	2,288	0,251112792
March	356160	1424639	3,12	2,288	0,831376108
April	260271	1041084	2,28	2,288	0
May	365429	1461714	3,20	2,288	0,912555167
June	568232	2272929	4,98	2,288	2,688783633
July	1445931	5783724	12,66	2,288	10,37598618
August	1490005	5960019	13,05	2,288	10,762
September	1202935	4811739	10,54	2,288	8,247737292
October	717494	2869974	6,28	2,288	3,996067552
November	391014	1564054	3,42	2,288	1,136637835
December	251189	1004754	2,20	2,288	0

Table B.6. Annual costs incurred by the compression chillers when a 2,288 MW absorption chiller is used

Maximum Usage Corresponds to the Maximum Capacity

13,05	1490004,798
2,288	261236,0903

For the months, which have electricity use above 261236,0903 kWh, compression chillers would be used.

	Average Electricity Consumption (KWh)	Consumption for Cooling (kWh)	Electricity Use for Compression Chillers (kWh)	Energy Use for Absorption Chillers (kWh)
January	1153110	373723,5484	112487,4581	1044944,361
February	1069293,75	289907,2984	28671,20806	1044944,361
March	1135546,25	356159,7984	94923,70806	1044944,361
April	1039657,5	260271,0484	0	1041084,194
May	1144815	365428,5484	104192,4581	1044944,361
June	1347618,75	568232,2984	306996,2081	1044944,361
July	2225317,5	1445931,048	1184694,958	1044944,361
August	2269391,25	1490004,798	1228768,708	1044944,361
September	1982321,25	1202934,798	941698,7081	1044944,361
October	1496880	717493,5484	456257,4581	1044944,361
November	1170400	391013,5484	129777,4581	1044944,361
December	1030575	251188,5484	0	1004754,194

Cooling by Compression Chiller (kWh)	18353873,32
Total Cost Incurred by Compression Chiller (YTL)	745966,8703
Total Cost Incurred by Compression Chiller ($)	548505,0517

Table B.7. Annual costs incurred by the absorption chillers and the total annual costs when a 2,288 MW absorption chiller is used

Annual Electricity Cost of the Existing Cooling System
925068,3952 13,05

One Absorption Cooling Machine with a capacity of 4,818 MW.
Capacity (kW) 2288
Required Water (m^3/h) 177,6556777 (At 120 C)

Working Hours
5455,976626 hours

Operational Costs ($)

Electricity	7163
Water Loss (Vaporization)	46637
Chemicals	5998
Maintenance	3599

Per Machine ($)	63396

Total Operational ($)	63396
Geothermal Water ($)	184110
Peaking Cost ($)	548505

Annual Cost ($)	796011

Capital Cost ($)	394046

Total ($)	394046

Cooling by Absorption Chiller (kWh)	12495282
Geothermal Energy Use (kWh)	17598988,73
Geothermal Water Use (m^3)	969285,2248

Total Working Hours for Full Capacity	5455,976626

Table B.8. Investment worth for a 2,288 MW compression chiller

Interest Rate	0,08
Annual Cost (Absorption)	796011,42
Annual Cost (Electricity)	925068,40

	Annual Cost (Absorption)	Annual Cost (Electricity)	Annual Income	Interest	Net Income	Worth of Investment
0						-394046,25
1	796011,42	925068,40	129056,97	-31523,70	97533,27	-296512,98
2	796011,42	925068,40	129056,97	-23721,04	105335,93	-191177,04
3	796011,42	925068,40	129056,97	-15294,16	113762,81	-77414,23
4	796011,42	925068,40	129056,97	-6193,14	122863,83	45449,60
5	796011,42	925068,40	129056,97	3635,97	132692,94	178142,54
6	796011,42	925068,40	129056,97	14251,40	143308,38	321450,91
7	796011,42	925068,40	129056,97	25716,07	154773,05	476223,96
8	796011,42	925068,40	129056,97	38097,92	167154,89	643378,85
9	796011,42	925068,40	129056,97	51470,31	180527,28	823906,13
10	796011,42	925068,40	129056,97	65912,49	194969,46	1018875,59
11	796011,42	925068,40	129056,97	81510,05	210567,02	1229442,61
12	796011,42	925068,40	129056,97	98355,41	227412,38	1456854,99
13	796011,42	925068,40	129056,97	116548,40	245605,37	1702460,37
14	796011,42	925068,40	129056,97	136196,83	265253,80	1967714,17
15	796011,42	925068,40	129056,97	157417,13	286474,11	2254188,27
16	796011,42	925068,40	129056,97	180335,06	309392,03	2563580,31

Table B.9. Annual costs incurred by the absorption chillers and the total annual costs when a 2,288 MW absorption chiller is used by considering whole year operation

If the Absorption Cooling Machine Works throughout the whole year

Required Cooling (kWh)	30849155,32
Total Working Hours	8760
Cost of Geothermal Water ($/kWh)	0,010082226
Cooling by Absorption Chiller (kWh)	19272000
Cooling by Compression Chillers (kWh)	11577155,32

Operational Costs ($)

Electricity	11500
Water Loss (Vaporization)	74880
Chemicals	9630
Maintenance	5778

Per Machine ($)	101787

Total Operational ($)	101787
Geothermal Water ($)	194305
Peaking Cost ($)	336248

Annual Cost ($)	632340

Table B.10. Investment worth for a 2,288 MW compression chiller by considering whole year operation

Interest Rate	0,08
Annual Cost (Absorption)	632340,41
Annual Cost (Electricity)	925068,40

	Annual Cost (Absorption)	Annual Cost (Electricity)	Annual Income	Interest	Net Income	Worth of Investment
0						-394046,25
1	632340,41	925068,40	292727,99	-31523,70	261204,29	-132841,96
2	632340,41	925068,40	292727,99	-10627,36	282100,63	149258,67
3	632340,41	925068,40	292727,99	11940,69	304668,68	453927,35
4	632340,41	925068,40	292727,99	36314,19	329042,18	782969,53
5	632340,41	925068,40	292727,99	62637,56	355365,55	1138335,08
6	632340,41	925068,40	292727,99	91066,81	383794,80	1522129,88
7	632340,41	925068,40	292727,99	121770,39	414498,38	1936628,26
8	632340,41	925068,40	292727,99	154930,26	447658,25	2384286,51
9	632340,41	925068,40	292727,99	190742,92	483470,91	2867757,41
10	632340,41	925068,40	292727,99	229420,59	522148,58	3389906,00
11	632340,41	925068,40	292727,99	271192,48	563920,47	3953826,47
12	632340,41	925068,40	292727,99	316306,12	609034,11	4562860,57
13	632340,41	925068,40	292727,99	365028,85	657756,83	5220617,41
14	632340,41	925068,40	292727,99	417649,39	710377,38	5930994,79
15	632340,41	925068,40	292727,99	474479,58	767207,57	6698202,36
16	632340,41	925068,40	292727,99	535856,19	828584,18	7526786,54

Table B.11. Required monthly compression chiller capacities when a 1,496 MW absorption chiller is used by considering whole year operation

Capacity (MW)	Electricity Consumption for Cooling(kWh)
13,05	1490004,798
2,2	251188,5484

Linear Regression for Capacity and Electricity Consumption

Intercept	0
Slope	8,75836E-06

	Electricity Consumption for Cooling (kWh)	Corresponding Cooling Load (kWh)	Required Maximum Capacities (MW)	Capacity of Absorption Cooling (MW)	Required Compression Chiller Capacity (MW)
January	373724	1494894	3,27	1,496	1,777205772
February	289907	1159629	2,54	1,496	1,043112792
March	356160	1424639	3,12	1,496	1,623376108
April	260271	1041084	2,28	1,496	0,783547814
May	365429	1461714	3,20	1,496	1,704555167
June	568232	2272929	4,98	1,496	3,480783633
July	1445931	5783724	12,66	1,496	11,16798618
August	1490005	5960019	13,05	1,496	11,554
September	1202935	4811739	10,54	1,496	9,039737292
October	717494	2869974	6,28	1,496	4,788067552
November	391014	1564054	3,42	1,496	1,928637835
December	251189	1004754	2,20	1,496	0,704

Table B.12. Annual costs incurred by the compression chillers when a 1,496 MW absorption chiller is used

Maximum Usage Corresponds to the Maximum Capacity

13,05	1490004,798
1,496	170808,2129

For the months, which have electricity use above 170808,2129 KWh, compression chillers would be used.

	Average Electricity Consumption (kWh)	Consumption for Cooling (kWh)	Electricity Use for Compression Chillers (kWh)	Energy Use for Absorption Chillers (kWh)
January	1153110	373723,5484	202915,3355	683232,8516
February	1069293,75	289907,2984	119099,0855	683232,8516
March	1135546,25	356159,7984	185351,5855	683232,8516
April	1039657,5	260271,0484	89462,83548	683232,8516
May	1144815	365428,5484	194620,3355	683232,8516
June	1347618,75	568232,2984	397424,0855	683232,8516
July	2225317,5	1445931,048	1275122,835	683232,8516
August	2269391,25	1490004,798	1319196,585	683232,8516
September	1982321,25	1202934,798	1032126,585	683232,8516
October	1496880	717493,5484	546685,3355	683232,8516
November	1170400	391013,5484	220205,3355	683232,8516
December	1030575	251188,5484	80380,33548	683232,8516

Cooling by Compression Chiller (kWh)	22650361,1
Total Cost Incurred by Compression Chiller (YTL)	922098,1783
Total Cost Incurred by Compression Chiller ($)	678013,3664

Table B.13. Annual costs incurred by the absorption chillers and the total annual costs when a 1,496 MW absorption chiller is used

If the Absorption Cooling Machine Works throughout the whole year

Required Cooling (kWh)	30849155,32
Total Working Hours	8760
Cost of Geothermal Water ($/kWh)	0,010082226
Cooling by Absorption Chiller (kWh)	13104960
Cooling by Compression Chillers (kWh)	17744195,32

Operational Costs ($)

Electricity	8854,041176
Water Loss (Vaporization)	48960
Chemicals	6296,296296
Maintenance	3777,777778

Per Machine ($)	67888,11525

Total Operational ($)	67888,11525
Geothermal Water ($)	132127,1696
Peaking Cost ($)	515364,4965

Annual Cost ($)	715379,7814

Table B.14. Investment worth for a 1,496 MW compression chiller

Interest Rate	0,08
Annual Cost (Absorption)	715379,78
Annual Cost (Electricity)	925068,40

	Annual Cost (Absorption)	Annual Cost (Electricity)	Annual Income	Interest	Net Income	Worth of Investment
0						-263877,50
1	715379,78	925068,40	209688,61	-21110,20	188578,41	-75299,09
2	715379,78	925068,40	209688,61	-6023,93	203664,69	128365,60
3	715379,78	925068,40	209688,61	10269,25	219957,86	348323,46
4	715379,78	925068,40	209688,61	27865,88	237554,49	585877,95
5	715379,78	925068,40	209688,61	46870,24	256558,85	842436,80
6	715379,78	925068,40	209688,61	67394,94	277083,56	1119520,36
7	715379,78	925068,40	209688,61	89561,63	299250,24	1418770,60
8	715379,78	925068,40	209688,61	113501,65	323190,26	1741960,87
9	715379,78	925068,40	209688,61	139356,87	349045,48	2091006,35
10	715379,78	925068,40	209688,61	167280,51	376969,12	2467975,47
11	715379,78	925068,40	209688,61	197438,04	407126,65	2875102,12
12	715379,78	925068,40	209688,61	230008,17	439696,78	3314798,91
13	715379,78	925068,40	209688,61	265183,91	474872,53	3789671,43
14	715379,78	925068,40	209688,61	303173,71	512862,33	4302533,76
15	715379,78	925068,40	209688,61	344202,70	553891,31	4856425,07
16	715379,78	925068,40	209688,61	388514,01	598202,62	5454627,69

APPENDIX C

DATA EXTRACTED FOR THE ABSORPTION COOLING SYSTEMS BY AVERAGING THE COOLING LOADS AND PER m^3 PRICING

Table C.1. Required monthly compression chiller capacities when a 4,818 MW absorption chiller is used

Capacity (MW)	Electricity Consumption for Cooling(kWh)
13,05	1490004,798
2,2	251188,5484

Linear Regression for Capacity and Electricity Consumption

Intercept	0
Slope	8,75836E-06

	Electricity Consumption for Cooling (kWh)	Corresponding Cooling Loads (kWh)	Required Maximum Capacities (MW)	Capacity of Absorption Cooling (MW)	Required Compression Chiller Capacity (MW)
January	373724	1494894	3,27	4,818	0
February	289907	1159629	2,54	4,818	0
March	356160	1424639	3,12	4,818	0
April	260271	1041084	2,28	4,818	0
May	365429	1461714	3,20	4,818	0
June	568232	2272929	4,98	4,818	0,158783633
July	1445931	5783724	12,66	4,818	7,845986184
August	1490005	5960019	13,05	4,818	8,232
September	1202935	4811739	10,54	4,818	5,717737292
October	717494	2869974	6,28	4,818	1,466067552
November	391014	1564054	3,42	4,818	0
December	251189	1004754	2,20	4,818	0

Table C.2. Annual costs incurred by the compression chillers when a 4,818 MW absorption chiller is used

Maximum Usage Corresponds to the Maximum Capacity

13,05	1490004,798
4,818	550102,921

For the months, which have electricity use above 550102,921 kWh, compression chillers would be used.

	Average Electricity Usage (kWh)	Use for Cooling (kWh)	Electricity Use (kWh) For Compression Chillers
January	1153110	373723,5484	0
February	1069293,75	289907,2984	0
March	1135546,25	356159,7984	0
April	1039657,5	260271,0484	0
May	1144815	365428,5484	0
June	1347618,75	568232,2984	18129,37742
July	2225317,5	1445931,048	895828,1274
August	2269391,25	1490004,798	939901,8774
September	1982321,25	1202934,798	652831,8774
October	1496880	717493,5484	167390,6274
November	1170400	391013,5484	0
December	1030575	251188,5484	0

Cooling by Compression Chiller (kWh)	10696327,55
Total Cost Incurred by Compression Chiller (YTL)	433833,2399
Total Cost Incurred by Compression Chiller ($)	318995,0293

Table C.3. Monthly geothermal water use when a 4,818 MW absorption chiller is used

Cooling Load for Absorption Chillers	Geothermal Water Consumption for Cooling(m^3/h)
2200411,7	400,5
1004754,2	182,9

Linear Regression for Capacity and electricity Consumption

Intercept	0
Slope	0,000182011

	Cooling Load Suplied by Absorption Chillers (kWh)	Monthly Geothermal Water Use (m^3)	Corresponding Maximum Geothermal Water Use (m^3/h)
January	1494894,19	124263,05	272,09
February	1159629,19	96394,15	211,07
March	1424639,19	118423,10	259,30
April	1041084,19	86540,10	189,49
May	1461714,19	121504,96	266,05
June	2200411,68	182909,17	400,50
July	2200411,68	182909,17	400,50
August	2200411,68	182909,17	400,50
September	2200411,68	182909,17	400,50
October	2200411,68	182909,17	400,50
November	1564054,19	130011,97	284,68
December	1004754,19	83520,17	182,88

Table C.4. Total additional geothermal water use for cooling when a 4,818 MW absorption chiller is used

Temperature of the Geothermal Water (C)		
From Cooling	100	Assumption
Used Directly for Heating	110	
Return Water	60	

Ratio of water that can be used for heating 0,8

	Monthly Geothermal Water Use for Cooling (m^3)	Monthly Geothermal Water Use for Heating (m^3)	Additional Geothermal Water Use for Heating (m^3)	Total Additional Geothermal Water Use for Cooling (m^3)
January	124263,05	70762	0	124263,0461
February	96394,15	68147	0	96394,15051
March	118423,10	67267	0	118423,1008
April	86540,10	48103,5	0	86540,10006
May	121504,96	0	0	121504,9593
June	182909,17	0	0	182909,1715
July	182909,17	0	0	182909,1715
August	182909,17	0	0	182909,1715
September	182909,17	0	0	182909,1715
October	182909,17	0	0	182909,1715
November	130011,97	41081	0	130011,9695
December	83520,17	52290	0	83520,16963

Table C.5. Annual costs incurred by the absorption chillers and the total annual costs when a 4,818 MW absorption chiller is used

Annual Electricity Cost of the Existing Cooling System

925068,3952 13,05

Cooling by Absorption Chiller (KWh)	20152827,77
Geothermal Energy Use (KWh)	30388188,83
Geothermal Water Use (m^3)	1673665,623

One Absorption Cooling Machine with a capacity of 4,818 MW.

Capacity (KW) 4818

Required Water (m^3/h) 400,5 (At 120 C)

Total Working Hours for Full Capacity	4178,940382

Working Hours

4178,94 hours

Operational Costs ($)

Electricity	109322
Water Loss (Vaporization)	75220,9
Chemicals	9673,47
Maintenance	5804,08

Per Machine ($)	200020

Capital Cost ($)	700000

Total Operational ($)	200020
Geothermal Water ($)	988373
Peaking Cost ($)	318995

Total ($)	700000

Annual Cost ($)	1507389

Table C.6. Investment worth for a 4,818 MW compression chiller

Interest Rate	0,08
Annual Cost (Absorption)	1507388,65
Annual Cost (Electricity)	925068,40

	Annual Cost (Absorption)	Annual Cost (Electricity)	Annual Income	Interest	Net Income	Worth of Investment
0						-700000,00
1	1507388,65	925068,40	-582320,25	-56000,00	-638320,25	-1338320,25
2	1507388,65	925068,40	-582320,25	-107065,62	-689385,87	-2027706,13
3	1507388,65	925068,40	-582320,25	-162216,49	-744536,74	-2772242,87
4	1507388,65	925068,40	-582320,25	-221779,43	-804099,68	-3576342,56
5	1507388,65	925068,40	-582320,25	-286107,40	-868427,66	-4444770,22
6	1507388,65	925068,40	-582320,25	-355581,62	-937901,87	-5382672,09
7	1507388,65	925068,40	-582320,25	-430613,77	-1012934,02	-6395606,11
8	1507388,65	925068,40	-582320,25	-511648,49	-1093968,74	-7489574,86
9	1507388,65	925068,40	-582320,25	-599165,99	-1181486,24	-8671061,10
10	1507388,65	925068,40	-582320,25	-693684,89	-1276005,14	-9947066,24
11	1507388,65	925068,40	-582320,25	-795765,30	-1378085,55	-11325151,80
12	1507388,65	925068,40	-582320,25	-906012,14	-1488332,40	-12813484,19
13	1507388,65	925068,40	-582320,25	-1025078,74	-1607398,99	-14420883,18
14	1507388,65	925068,40	-582320,25	-1153670,65	-1735990,91	-16156874,09
15	1507388,65	925068,40	-582320,25	-1292549,93	-1874870,18	-18031744,28
16	1507388,65	925068,40	-582320,25	-1442539,54	-2024859,80	-20056604,07

Table C.7. Required monthly compression chiller capacities when a 2,288 MW absorption chiller is used

Capacity (MW)	Electricity Consumption for Cooling (kWh)
13,05	1490004,798
2,2	251188,5484

Linear Regression for Capacity and Electricity Consumption

Intercept	0
Slope	8,75836E-06

	Electricity Consumption for Cooling (kWh)	Corresponding Cooling Loads (kWh)	Required Maximum Capacities (MW)	Capacity of Absorption Cooling (MW)	Required Compression Chiller Capacity (MW)
January	373724	1494894	3,27	2,288	0,985205772
February	289907	1159629	2,54	2,288	0,251112792
March	356160	1424639	3,12	2,288	0,831376108
April	260271	1041084	2,28	2,288	0
May	365429	1461714	3,20	2,288	0,912555167
June	568232	2272929	4,98	2,288	2,688783633
July	1445931	5783724	12,66	2,288	10,37598618
August	1490005	5960019	13,05	2,288	10,762
September	1202935	4811739	10,54	2,288	8,247737292
October	717494	2869974	6,28	2,288	3,996067552
November	391014	1564054	3,42	2,288	1,136637835
December	251189	1004754	2,20	2,288	0

Table C.8. Annual costs incurred by the compression chillers when a 2,288 MW absorption chiller is used

Maximum Usage Corresponds to the Maximum Capacity

13,05	1490004,798
2,288	261236,0903

For the months, which have electricity use above 261236,0903 kWh, compression chillers would be used.

	Average Electricity Usage (kWh)	Use for Cooling (kWh)	Electricity Use (kWh) For Compression Chillers
January	1153110	373723,5484	112487,4581
February	1069293,75	289907,2984	28671,20806
March	1135546,25	356159,7984	94923,70806
April	1039657,5	260271,0484	0
May	1144815	365428,5484	104192,4581
June	1347618,75	568232,2984	306996,2081
July	2225317,5	1445931,048	1184694,958
August	2269391,25	1490004,798	1228768,708
September	1982321,25	1202934,798	941698,7081
October	1496880	717493,5484	456257,4581
November	1170400	391013,5484	129777,4581
December	1030575	251188,5484	0

Cooling by Compression Chiller (kWh)	18353873,32
Total Cost Incurred by Compression Chiller (YTL)	745966,8703
Total Cost Incurred by Compression Chiller ($)	548505,0517

Table C.9. Monthly geothermal water use when a 2,288 MW absorption chiller is used

Cooling Load for Absorption Chillers	Geothermal Water Consumption for Cooling(m^3/h)
1044944,4	177,7
1004754,2	170,8

Linear Regression for Capacity and electricity Consumption

Intercept	3,41061E-13
Slope	0,000170014

	Cooling Load Suplied by Absorption Chillers (kWh)	Monthly Geothermal Water Use (m^3)	Corresponding Maximum Geothermal Water Use (m^3/h)
January	1044944,36	81133,00	177,66
February	1044944,36	81133,00	177,66
March	1044944,36	81133,00	177,66
April	1041084,19	80833,28	177,00
May	1044944,36	81133,00	177,66
June	1044944,36	81133,00	177,66
July	1044944,36	81133,00	177,66
August	1044944,36	81133,00	177,66
September	1044944,36	81133,00	177,66
October	1044944,36	81133,00	177,66
November	1044944,36	81133,00	177,66
December	1004754,19	78012,50	170,82

Table C.10. Total additional geothermal water use for cooling when a 2,288 MW absorption chiller is used

Temperature of the Geothermal Water (C)		
From Cooling	95	Assumption
Used Directly for Heating	110	
Return Water	60	

Ratio of water that can be used for heating 0,7

	Monthly Geothermal Water Use for Cooling (m^3)	Monthly Geothermal Water Use for Heating (m^3)	Additional Geothermal Water Use for Heating (m^3)	Total Additional Geothermal Water Use for Cooling (m^3)
January	81133,00	70762	13968,89994	13968,89994
February	81133,00	68147	11353,89994	11353,89994
March	81133,00	67267	10473,89994	10473,89994
April	80833,28	48103,5	0	80833,28366
May	81133,00	0	0	81133,00008
June	81133,00	0	0	81133,00008
July	81133,00	0	0	81133,00008
August	81133,00	0	0	81133,00008
September	81133,00	0	0	81133,00008
October	81133,00	0	0	81133,00008
November	81133,00	41081	0	81133,00008
December	78012,50	52290	0	78012,50008

Table C.11. Annual costs incurred by the absorption chillers and the total annual costs when a 2,288 MW absorption chiller is used

Annual Electricity Cost of the Existing Cooling System
925068,3952 13,05

Cooling by Absorption Chiller (KWh)	12495282
Geothermal Energy Use (KWh)	17598988,73
Geothermal Water Use (m^3)	969285,2248

One Absorption Cooling Machine with a capacity of 2,288 MW.

Capacity (KW) 2288

Required Water (m^3/h) 177,656 (At 120 C)

Total Working Hours for Full Capacity	5455,976626

Working Hours
5455,98 hours

Operational Costs ($)

Electricity	7163
Water Loss (Vaporization)	46637
Chemicals	5998
Maintenance	3599

Per Machine ($)	63396

Capital Cost ($)	394046

Total Operational ($)	63396
Geothermal Water ($)	447190
Peaking Cost ($)	548505

Total ($)	394046

Annual Cost ($)	1059091

Table C.12. Investment worth for a 2,288 MW compression chiller

Interest Rate	0,08
Annual Cost (Absorption)	1059091,46
Annual Cost (Electricity)	925068,40

	Annual Cost (Absorption)	Annual Cost (Electricity)	Annual Income	Interest	Net Income	Worth of Investment
0						-394046,25
1	1059091,46	925068,40	-134023,06	-31523,70	-165546,76	-559593,01
2	1059091,46	925068,40	-134023,06	-44767,44	-178790,50	-738383,51
3	1059091,46	925068,40	-134023,06	-59070,68	-193093,74	-931477,26
4	1059091,46	925068,40	-134023,06	-74518,18	-208541,24	-1140018,50
5	1059091,46	925068,40	-134023,06	-91201,48	-225224,54	-1365243,04
6	1059091,46	925068,40	-134023,06	-109219,44	-243242,50	-1608485,54
7	1059091,46	925068,40	-134023,06	-128678,84	-262701,90	-1871187,45
8	1059091,46	925068,40	-134023,06	-149695,00	-283718,06	-2154905,50
9	1059091,46	925068,40	-134023,06	-172392,44	-306415,50	-2461321,00
10	1059091,46	925068,40	-134023,06	-196905,68	-330928,74	-2792249,75
11	1059091,46	925068,40	-134023,06	-223379,98	-357403,04	-3149652,79
12	1059091,46	925068,40	-134023,06	-251972,22	-385995,28	-3535648,07
13	1059091,46	925068,40	-134023,06	-282851,85	-416874,91	-3952522,98
14	1059091,46	925068,40	-134023,06	-316201,84	-450224,90	-4402747,88
15	1059091,46	925068,40	-134023,06	-352219,83	-486242,89	-4888990,77
16	1059091,46	925068,40	-134023,06	-391119,26	-525142,32	-5414133,09

Table C.13. Annual costs incurred by the absorption chillers and the total annual costs when a 2,288 MW absorption chiller is used by considering whole year operation

If the Absorption Cooling Machine Works throughout the whole year

Required Cooling (kWh)	30849155,32
Total Working Hours	8760
Cost of Geothermal Water ($/m^3)	0,5698
Cooling by Absorption Chiller (kWh)	19272000
Cooling by Compression Chillers (kWh)	11577155,32

Operational Costs ($)

Electricity	11500
Water Loss (Vaporization)	74880
Chemicals	9630
Maintenance	5778

Per Machine ($)	101787

Total Operational ($)	101787
Geothermal Water ($)	654562
Peaking Cost ($)	336248

Annual Cost ($)	1092597

Table C.14. Investment worth for a 2,288 MW compression chiller by considering whole year operation

Interest Rate	0,08
Annual Cost (Absorption)	1092597,45
Annual Cost (Electricity)	925068,40

	Annual Cost (Absorption)	Annual Cost (Electricity)	Annual Income	Interest	Net Income	Worth of Investment
0						-394046,25
1	1092597,45	925068,40	-167529,05	-31523,70	-199052,75	-593099,00
2	1092597,45	925068,40	-167529,05	-47447,92	-214976,97	-808075,98
3	1092597,45	925068,40	-167529,05	-64646,08	-232175,13	-1040251,11
4	1092597,45	925068,40	-167529,05	-83220,09	-250749,14	-1291000,25
5	1092597,45	925068,40	-167529,05	-103280,02	-270809,07	-1561809,33
6	1092597,45	925068,40	-167529,05	-124944,75	-292473,80	-1854283,13
7	1092597,45	925068,40	-167529,05	-148342,65	-315871,70	-2170154,83
8	1092597,45	925068,40	-167529,05	-173612,39	-341141,44	-2511296,27
9	1092597,45	925068,40	-167529,05	-200903,70	-368432,76	-2879729,02
10	1092597,45	925068,40	-167529,05	-230378,32	-397907,38	-3277636,40
11	1092597,45	925068,40	-167529,05	-262210,91	-429739,97	-3707376,36
12	1092597,45	925068,40	-167529,05	-296590,11	-464119,16	-4171495,53
13	1092597,45	925068,40	-167529,05	-333719,64	-501248,70	-4672744,22
14	1092597,45	925068,40	-167529,05	-373819,54	-541348,59	-5214092,81
15	1092597,45	925068,40	-167529,05	-417127,43	-584656,48	-5798749,29
16	1092597,45	925068,40	-167529,05	-463899,94	-631429,00	-6430178,29

Table C.15. Annual costs incurred by the absorption chillers and the total annual costs when a 1,496 MW absorption chiller is used by considering whole year operation

If the Absorption Cooling Machine Works throughout the whole year

Required Cooling (kWh)	30849155,32
Total Working Hours	8760
Cost of Geothermal Water ($/m^3)	0,5698
Cooling by Absorption Chiller (kWh)	13104960
Cooling by Compression Chillers (kWh)	17744195,32

Operational Costs ($)

Electricity	14044
Water Loss (Vaporization)	48960
Chemicals	6296
Maintenance	3778
Per Machine ($)	73078

Total Operational ($)	73078
Geothermal Water ($)	364484
Peaking Cost ($)	515364

Annual Cost ($)	952927

Table C.16. Investment worth for a 1,496 MW compression chiller by considering whole year operation

Interest Rate	0,08
Annual Cost (Absorption)	952926,80
Annual Cost (Electricity)	925068,40

	Annual Cost (Absorption)	Annual Cost (Electricity)	Annual Income	Interest	Net Income	Worth of Investment
0						-263877,50
1	952926,80	925068,40	-27858,41	-21110,20	-48968,61	-312846,11
2	952926,80	925068,40	-27858,41	-25027,69	-52886,10	-365732,21
3	952926,80	925068,40	-27858,41	-29258,58	-57116,99	-422849,19
4	952926,80	925068,40	-27858,41	-33827,94	-61686,35	-484535,54
5	952926,80	925068,40	-27858,41	-38762,84	-66621,25	-551156,79
6	952926,80	925068,40	-27858,41	-44092,54	-71950,95	-623107,75
7	952926,80	925068,40	-27858,41	-49848,62	-77707,03	-700814,77
8	952926,80	925068,40	-27858,41	-56065,18	-83923,59	-784738,37
9	952926,80	925068,40	-27858,41	-62779,07	-90637,48	-875375,85
10	952926,80	925068,40	-27858,41	-70030,07	-97888,48	-973264,32
11	952926,80	925068,40	-27858,41	-77861,15	-105719,56	-1078983,88
12	952926,80	925068,40	-27858,41	-86318,71	-114177,12	-1193161,00
13	952926,80	925068,40	-27858,41	-95452,88	-123311,29	-1316472,29
14	952926,80	925068,40	-27858,41	-105317,78	-133176,19	-1449648,48
15	952926,80	925068,40	-27858,41	-115971,88	-143830,29	-1593478,77
16	952926,80	925068,40	-27858,41	-127478,30	-155336,71	-1748815,48

APPENDIX D

DATA EXTRACTED FOR THE ABSORPTION COOLING SYSTEMS BY APPLYING LINEAR REGRESSION FOR COOLING LOADS AND PER kWh PRICING

Table D.1. Required monthly compression chiller capacities when a 4,818 MW absorption chiller is used

Capacity (MW)	Electricity Consumption for Cooling(KWh)
13,05	2819418,822
2,2	475304,3225

Linear Regression for Capacity and electricity Consumption

Intercept	0
Slope	4,62861E-06

	Electricity Consumption for Cooling (KWh)	Corresponding Cooling Load (KWh)	Required Maximum Capacities (MW)	Capacity of Absorption Cooling (MW)	Required Compression Chiller Capacity (MW)
January	928852	3715407	4,30	4,818	0
February	475304	1901217	2,20	4,818	0
March	863036	3452143	3,99	4,818	0
April	869233	3476931	4,02	4,818	0
May	993091	3972363	4,60	4,818	0
June	1230439	4921755	5,70	4,818	0,877225735
July	2819419	11277675	13,05	4,818	8,232
August	2249216	8996865	10,41	4,818	5,592753016
September	1421333	5685333	6,58	4,818	1,760802593
October	1073558	4294233	4,97	4,818	0,151086536
November	794786	3179145	3,68	4,818	0
December	834950	3339801	3,86	4,818	0

Table D.2. Annual costs incurred by the compression chillers when a 4,818 MW absorption chiller is used

Maximum Usage Corresponds to the Maximum Capacity

13,05	2819418,822
4,818	1040916,466

For the months, which have electricity use above 1040916,466 kWh, compression chillers would be used.

	Average Electricity Usage (kWh)	Use for Cooling (kWh)	Electricity Use for Compression Chillers (kWh)	Energy Use for Absorption Chillers (kWh)
January	1341406,5	928851,8225	0	3715407,29
February	887859,0001	475304,3225	0	1901217,29
March	1275590,5	863035,8225	0	3452143,29
April	1281787,5	869232,8225	0	3476931,29
May	1405645,5	993090,8225	0	3972363,29
June	1642993,5	1230438,822	189522	4163665,865
July	3231973,5	2819418,822	1778502	4163665,865
August	2661771	2249216,322	1208300	4163665,865
September	1833888	1421333,322	380417	4163665,865
October	1486113	1073558,322	32642	4163665,865
November	1207341	794786,3225	0	3179145,29
December	1247505	834950,3226	0	3339801,29

Cooling by Compression Chiller (kWh)	14357533,12
Total Cost Incurred by Compression Chiller (YTL)	584254,2361
Total Cost Incurred by Compression Chiller ($)	429598,703

Table D.3. Annual costs incurred by the absorption chillers and the total annual costs when a 4,818 MW absorption chiller is used

Annual Electricity Cost of the Existing Cooling System

Cost ($) 1749429

Capacity (MW) 13,05

One Absorption Cooling Machine with a capacity of 4,818 MW.

Capacity (KW) 4818

Required Water (m^3/h) 400,5 (At 120 C)

Cooling by Absorption Chiller (KWh)	43855338,36
Geothermal Energy Use (KWh)	66128898,54
Geothermal Water Use (m^3)	3642127,696

Total Working Hours for Full Capacity	9093,951801

Working Hours

9093,95 hours <u>Exceeds total annual working hours!!!</u>

Operational Costs ($)

Electricity	237899
Water Loss (Vaporization)	163691
Chemicals	21050,8
Maintenance	12630,5

Per Machine ($)	435272

Capital Cost ($)	700000

Total Operational ($)	435272
Geothermal Water ($)	690852
Peaking Cost ($)	429599

Total ($)	700000

Annual Cost ($)	1555723

Table D.4. Investment worth for a 4,818 MW compression chiller

Interest Rate	0,08
Annual Cost (Absorption)	1555722,59
Annual Cost (Electricity)	1749428,54

	Annual Cost (Absorption)	Annual Cost (Electricity)	Annual Income	Interest	Net Income	Worth of Investment
0						-700000,00
1	1555722,59	1749428,54	193705,95	-56000,00	137705,95	-562294,05
2	1555722,59	1749428,54	193705,95	-44983,52	148722,43	-413571,62
3	1555722,59	1749428,54	193705,95	-33085,73	160620,22	-252951,40
4	1555722,59	1749428,54	193705,95	-20236,11	173469,84	-79481,55
5	1555722,59	1749428,54	193705,95	-6358,52	187347,43	107865,87
6	1555722,59	1749428,54	193705,95	8629,27	202335,22	310201,10
7	1555722,59	1749428,54	193705,95	24816,09	218522,04	528723,14
8	1555722,59	1749428,54	193705,95	42297,85	236003,80	764726,94
9	1555722,59	1749428,54	193705,95	61178,16	254884,11	1019611,05
10	1555722,59	1749428,54	193705,95	81568,88	275274,84	1294885,88
11	1555722,59	1749428,54	193705,95	103590,87	297296,82	1592182,71
12	1555722,59	1749428,54	193705,95	127374,62	321080,57	1913263,28
13	1555722,59	1749428,54	193705,95	153061,06	346767,01	2260030,29
14	1555722,59	1749428,54	193705,95	180802,42	374508,38	2634538,67
15	1555722,59	1749428,54	193705,95	210763,09	404469,05	3039007,71
16	1555722,59	1749428,54	193705,95	243120,62	436826,57	3475834,28

APPENDIX E

DATA EXTRACTED FOR THE ABSORPTION COOLING SYSTEMS BY APPLYING LINEAR REGRESSION FOR COOLING LOADS AND PER m^3 PRICING

Table E.1. Required monthly compression chiller capacities when a 4,818 MW absorption chiller is used

Capacity (MW)	Electricity Consumption for Cooling (kWh)
13,05	2819418,822
2,2	475304,3225

Linear Regression for Capacity and electricity Consumption

Intercept	0
Slope	4,62861E-06

	Electricity Consumption for Cooling (kWh)	Corresponding Cooling Load (kWh)	Required Maximum Capacities (MW)	Capacity of Absorption Cooling (MW)	Required Compression Chiller Capacity (MW)
January	928852	3715407	4,30	4,818	0
February	475304	1901217	2,20	4,818	0
March	863036	3452143	3,99	4,818	0
April	869233	3476931	4,02	4,818	0
May	993091	3972363	4,60	4,818	0
June	1230439	4921755	5,70	4,818	0,877225735
July	2819419	11277675	13,05	4,818	8,232
August	2249216	8996865	10,41	4,818	5,592753016
September	1421333	5685333	6,58	4,818	1,760802593
October	1073558	4294233	4,97	4,818	0,151086536
November	794786	3179145	3,68	4,818	0
December	834950	3339801	3,86	4,818	0

Table E.2. Annual costs incurred by the compression chillers when a 4,818 MW absorption chiller is used

Maximum Usage Corresponds to the Maximum Capacity

13,05	2819418,822
4,818	1040916,466

For the months, which have electricity use above 1040916,466 kWh, compression chillers would be used.

	Average Electricity Usage (kWh)	Use for Cooling (kWh)	Electricity Use (kWh) For Compression Chillers
January	1341406,5	928851,8225	0
February	887859,0001	475304,3225	0
March	1275590,5	863035,8225	0
April	1281787,5	869232,8225	0
May	1405645,5	993090,8225	0
June	1642993,5	1230438,822	189522,3562
July	3231973,5	2819418,822	1778502,356
August	2661771	2249216,322	1208299,856
September	1833888	1421333,322	380416,8562
October	1486113	1073558,322	32641,85616
November	1207341	794786,3225	0
December	1247505	834950,3226	0

Cooling by Compression Chiller (KWh)	14357533,12
Total Cost Incurred by Compression Chiller (YTL)	584254,2361
Total Cost Incurred by Compression Chiller ($)	429598,703

Table E.3. Monthly geothermal water use when a 4,818 MW absorption chiller is used

Cooling Load for Absorption Chillers	Geothermal Water Consumption for Cooling(m^3/h)
4163665,9	400,5
1901217,3	182,9

Linear Regression for Capacity and electricity Consumption

Intercept	0
Slope	9,61893E-05

	Electricity Use for Absorption Chillers (KWh)	Monthly Geothermal Water Use (m^3)	Corresponding Maximum Geothermal Water Use (m^3/h)
January	3715407,29	308843,15	357,38
February	1901217,29	158038,64	182,88
March	3452143,29	286959,33	332,06
April	3476931,29	289019,83	334,44
May	3972363,29	330202,61	382,10
June	4163665,87	346104,63	400,50
July	4163665,87	346104,63	400,50
August	4163665,87	346104,63	400,50
September	4163665,87	346104,63	400,50
October	4163665,87	346104,63	400,50
November	3179145,29	264266,38	305,80
December	3339801,29	277620,91	321,25

Table E.4. Total additional geothermal water use for cooling

Temperature of the Geothermal Water (C)

From Cooling	100	Assumption
Used Directly for Heating	110	
Return Water	60	

Ratio of water that can be used for heating 0,8

	Monthly Geothermal Water Use for Cooling (m^3)	Monthly Geothermal Water Use for Heating (m^3)	Additional Geothermal Water Use for Heating (m^3)	Total Additional Geothermal Water Use for Cooling (m^3)
January	308843,15	70762	0	308843,147
February	158038,64	68147	0	158038,6443
March	286959,33	67267	0	286959,333
April	289019,83	48103,5	0	289019,8349
May	330202,61	0	0	330202,6087
June	346104,63	0	0	346104,631
July	346104,63	0	0	346104,631
August	346104,63	0	0	346104,631
September	346104,63	0	0	346104,631
October	346104,63	0	0	346104,631
November	264266,38	41081	0	264266,3804
December	277620,91	52290	0	277620,9068

Table E.5. Annual costs incurred by the absorption chillers and the total annual costs when a 4,818 MW absorption chiller is used

Annual Electricity Cost of the Existing Cooling System

Cost ($)	1749429
Capacity (MW)	13,05

One Absorption Cooling Machine with a capacity of 4,818 MW.

Capacity (KW)	4818	
Required Water (m^3/h)	400,5	(At 120 C)

Cooling by Absorption Chiller (KWh)	43855338,36
Geothermal Energy Use (KWh)	66128898,54
Geothermal Water Use (m^3)	3642127,696

Total Working Hours for Full Capacity	9093,951801

Working Hours

9093,95 hours Exceeds total annual working hours!!!

Operational Costs ($)

Electricity	237899
Water Loss (Vaporization)	163691
Chemicals	21050,8
Maintenance	12630,5

Per Machine ($)	435272

Capital Cost ($)	700000

Total Operational ($)	435272
Geothermal Water ($)	2152354
Peaking Cost ($)	429599

Total ($)	700000

Annual Cost ($)	3017225

Table E.6. Investment worth for a 4,818 MW compression chiller

Interest Rate	0,08
Annual Cost (Absorption)	3017224,79
Annual Cost (Electricity)	1749428,54

	Annual Cost (Absorption)	Annual Cost (Electricity)	Annual Income	Interest	Net Income	Worth of Investment
0						-700000,00
1	3017224,79	1749428,54	-1267796,25	-56000,00	-1323796,25	-2023796,25
2	3017224,79	1749428,54	-1267796,25	-161903,70	-1429699,95	-3453496,20
3	3017224,79	1749428,54	-1267796,25	-276279,70	-1544075,95	-4997572,15
4	3017224,79	1749428,54	-1267796,25	-399805,77	-1667602,02	-6665174,17
5	3017224,79	1749428,54	-1267796,25	-533213,93	-1801010,18	-8466184,35
6	3017224,79	1749428,54	-1267796,25	-677294,75	-1945091,00	-10411275,35
7	3017224,79	1749428,54	-1267796,25	-832902,03	-2100698,28	-12511973,63
8	3017224,79	1749428,54	-1267796,25	-1000957,89	-2268754,14	-14780727,77
9	3017224,79	1749428,54	-1267796,25	-1182458,22	-2450254,47	-17230982,24
10	3017224,79	1749428,54	-1267796,25	-1378478,58	-2646274,83	-19877257,07
11	3017224,79	1749428,54	-1267796,25	-1590180,57	-2857976,82	-22735233,89
12	3017224,79	1749428,54	-1267796,25	-1818818,71	-3086614,96	-25821848,85
13	3017224,79	1749428,54	-1267796,25	-2065747,91	-3333544,16	-29155393,01
14	3017224,79	1749428,54	-1267796,25	-2332431,44	-3600227,69	-32755620,70
15	3017224,79	1749428,54	-1267796,25	-2620449,66	-3888245,91	-36643866,61
16	3017224,79	1749428,54	-1267796,25	-2931509,33	-4199305,58	-40843172,18

APPENDIX F

RESULTS OF REGRESSION ANALYSIS APPLIED ON EACH MONTH

Table F.1.Regression analysis of January

Regression Statistics	
Multiple R	0,861750913
R Square	0,742614636

ANOVA

	df	*SS*	*MS*	*F*
Regression	5	30724294703	6144858941	8,655674389
Residual	3	10648839127	3549613042	
Total	8	41373133830		

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-109794741	37718523,8	-2,910897086	0,061951524	-229832030,3	10242548
Slope	55429,50001	18840,41678	2,942052751	0,060410127	-4529,170999	115388,17

Table F.2.Regression analysis of February

Regression Statistics	
Multiple R	0,661135727
R Square	0,43710045

ANOVA

	df	*SS*	*MS*	*F*
Regression	4	13436150411	3359037603	1,553031796
Residual	2	17303123408	8651561704	
Total	6	30739273819		

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	104824051,5	83256454,95	1,259050142	0,335054741	-253399811,1	463047914
Slope	-51838,49998	41597,02321	-1,246206963	0,338864271	-230816,1701	127139,17

Table F.3.Regression analysis of March

Regression Statistics	
Multiple R	0,65866428
R Square	0,433838634

ANOVA

	df	*SS*	*MS*	*F*
Regression	5	13390110562	2678022112	2,298842664
Residual	3	17474154418	5824718139	
Total	8	30864264980		

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-72092372,01	48317186,65	-1,492064771	0,232497252	-225859368,4	81674624
Slope	36592,50001	24134,45284	1,516193478	0,226732638	-40214,17233	113399,17

Table F.4.Regression analysis of April

Regression Statistics	
Multiple R	0,572200264
R Square	0,327413142

ANOVA

	df	*SS*	*MS*	*F*
Regression	5	43994699122	8798939824	1,46039045
Residual	3	90375897308	30125299103	
Total	8	1,34371E+11		

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-131706855	109882837,4	-1,198611704	0,316728381	-481403413	217989703
Slope	66328,50001	54886,51848	1,208466156	0,313433819	-108345,0618	241002,06

Table F.5.Regression analysis of May

Regression Statistics	
Multiple R	0,769664338
R Square	0,592383193

ANOVA

	df	*SS*	*MS*	*F*
Regression	5	65248429523	13049685905	4,359853532
Residual	3	44897216648	14965738883	
Total	8	1,10146E+11		

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-160551237	77448545,01	-2,073005206	0,12986816	-407027304,2	85924830
Slope	80776,50001	38685,57727	2,088026229	0,128017777	-42338,38792	203891,39

Table F.6.Regression analysis of June

Regression Statistics	
Multiple R	0,690956567
R Square	0,477420978

ANOVA

	df	*SS*	*MS*	*F*
Regression	5	76451415323	15290283065	2,740758568
Residual	3	83682761647	27894253882	
Total	8	1,60134E+11		

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-173667189	105735678,4	-1,642465359	0,199035258	-510165623,9	162831246
Slope	87436,50001	52815,01102	1,655523654	0,196393978	-80644,59434	255517,59

Table F.7.Regression analysis of July

Regression Statistics	
Multiple R	0,621938368
R Square	0,386807334

ANOVA

	df	*SS*	*MS*	*F*
Regression	4	4,13615E+11	1,03404E+11	1,261617613
Residual	2	6,5569E+11	3,27845E+11	
Total	6	1,0693E+12		

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-573438106,3	512512937	-1,118875378	0,37953924	-2778604829	1,632E+09
Slope	287615,9999	256064,3802	1,123217527	0,378061632	-814140,8717	1389372,9

Table F.8.Regression analysis of August

Regression Statistics	
Multiple R	0,735148697
R Square	0,540443607

ANOVA

	df	*SS*	*MS*	*F*
Regression	4	62841578861	15710394715	2,352023016
Residual	2	53436193807	26718096904	
Total	6	1,16278E+11		

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-222115771,4	146309801,2	-1,518119563	0,268296408	-851636475,3	407404932
Slope	112108,5	73100,06415	1,533630665	0,264851303	-202415,9096	426632,91

Table F.9.Regression analysis of September

Regression Statistics	
Multiple R	0,344760469
R Square	0,118859781

ANOVA

	df	*SS*	*MS*	*F*
Regression	4	8992828451	2248207113	0,269786303
Residual	2	66666308468	33333154234	
Total	6	75659136919		

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	86864935,47	163421377,1	0,531539613	0,648174775	-616280988,4	790010859
Slope	-42409,49999	81649,43873	-0,519409572	0,655239531	-393718,925	308899,93

Table F.10.Regression analysis of October

Regression Statistics	
Multiple R	0,10703184
R Square	0,011455815

ANOVA

	df	*SS*	*MS*	*F*
Regression	1	1450674540	1450674540	0,023177143
Residual	2	1,25181E+11	62590741605	
Total	3	1,26632E+11		

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	27302493	169301567	0,161265448	0,886702349	-701143863,6	755748850
Slope	-12876	84576,75575	-0,15224041	0,89296816	-376780,6623	351028,66

Table F.11.Regression analysis of November

Regression Statistics	
Multiple R	0,34445353
R Square	0,118648235

ANOVA

	df	*SS*	*MS*	*F*
Regression	1	1308334860	1308334860	0,269241498
Residual	2	9718671690	4859335845	
Total	3	11027006550		

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-23309799	47173096,74	-0,494133322	0,670150003	-226279393,8	179659796
Slope	12228	23565,92175	0,51888486	0,65554647	-89168,04814	113624,05

Table F.12.Regression analysis of December

Regression Statistics	
Multiple R	0,871873085
R Square	0,760162677

ANOVA

	df	*SS*	*MS*	*F*
Regression	3	5882328113	1960776038	3,169492834
Residual	1	1855920938	1855920938	
Total	4	7738249050		

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-107488657,6	60955354,69	-1,763399756	0,328410912	-881996555,9	667019241
Slope	54232,50003	30462,44359	1,78030695	0,325810677	-332827,8867	441292,89

APPENDIX G

PRICE OFFERS AND SPECIFICATIONS FOR THE SELECTED ABSORPTION COOLING MACHINES

SOĞUTMA GRUBU SİSTEMİ		Absorpsiyon
		120 °C Sıcak Su ile
York Chiller Model No		**YIA - HW - 14F3**
Soğutma Kapasitesi	kw	4,813
Soğutucu Akışkan		Li-Br + H2O
Boyutlar (BxExY)	mm	9310 x 2400 x 4250
Çalışma Ağırlığı	kg	41,140
Chiller Elektrik Gücü	kw	12
Chiller Isıl Güç Sarfiyatı (120/104.4 °C, 400 m3/h)	kw	7,266
Chiller Evaporatör Su Pompası Motor Gücü (830 m3/h, 20 mSS)	kw	55
Sıcak Su Pompası Motor Gücü (400 m3/h, 20 mSS)	kw	30
Baltimore Soğutma Kulesi Model No		**(4) S - 3754 - PM**
Soğutma Kapasitesi		347 l/s, 38.2 / 30 °C, 25 °C yt
Boyutlar (BxExY)	mm	12100 x 6180 x 3590
Çalışma Ağırlığı	kg	35,800
Fan Elektrik Gücü	kw	120
Kule Su Pompası Motor Gücü (1250 m3/h, 25 mSS)	kw	110
Toplam Su Sarfiyatı (Buharlaşma)	m3/h	18
TAHMİNİ YATIRIM MALİYETİ		
Chiller Şantiye Teslimi	$	330,000
Soğ. Kulesi Şantiye Teslimi	$	125,000
Chiller & Kule Montaj	$	30,000
Evaporatör Hattı Borulama & Pompa	$	75,000
Sıcak Su Hattı Borulama & Pompa	$	60,000
Soğ. Kulesi Borulama & Pompa	$	75,000
Soğ. Kulesi suyu Islahı & Dozajlama Sis.	$	5,000
	$	**700,000**
TAHMİNİ YILLIK İŞLETME MALİYETLERİ		
Toplam Çalışma Saati (6 ay, 12 saat/gün)	saat	2,160
Toplam Elektrik Kurulu Güç	kw	327
Elektrik $/kw	$	0.08
Su $/m3/h	$	1
Elektrik Maliyeti	$	56,506
Su Maliyeti	$	38,880
Kimyasal Maliyeti	$	5,000
Periyodik Bakım Maliyeti	$	3,000
	$	**103,386**
		- Çok Düşük İşletme Maliyeti - Düşük Tamirat Maliyeti - Düşük Elek. Tesisat Maliyeti - Düşük Ses Seviyeleri
		- Yüksek Yatırım Maliyeti - İç/Dış Mahalde Yer İhtiyacı - Kuleden Su Kayıbı Var

HAKAN ODABASI / YORK Türkiye 18.10.2002

Figure G.1. Price offer and specifications for 4,818 MW absorption cooling machine

27-05-05 10:01 0232 4597790 FORM AS 005

0232 4597790

Hot Water Fired Machine

Technical specification for Vapour Absorption Chiller

Date : 26.May.05

THERMAX

Client | Project

Model

Model	LT 52 S	Capacity	2288 ±3% kW
			651.0 ±3% TR

Tube Material

Evaporator	Copper
Absorber	Copper
Condensor	Copper

Chilled Water

Temperature	In 12 Out 7 °C
Flow	393.7 m³/hr
Fouling Factor	0.00005 (metric)
Glycol	0 %
Fric.Loss/Pr.Drop	7.4 / 9.3 mLC
Passes (Evap)	3 Conn. 250 NB(mm)

Cooling Water

Temperature	In 29.4 Out 36.7 °C
Flow	651 m³/hr
Fouling Factor	0.00005 (metric)
Glycol	0 %
Fric.Loss/Pr.Drop	9.6 / 8.2 mLC
Passes (Abso/Cond)	2 / 1 Conn. 300 NB(mm)

Power Supply

Supply Power	415V±10%, 50Hz±5%, 3Ph
Power Consumption	11.3 KVA
Abso Pump Rating	3 kW
Refr Pump Rating	1.5 kW
Vac Pump Rating	0.75 kW

Hot Water

Temperature	In 110 Out 95 °C
Flow	194 ±3% m³/hr
Glycol	0 %
Fric.Loss/Pr Drop	6.7 / 6.7 mLC
Passes (Gen)	3 Conn. 200 NB(mm)

Dimensions

Length	8200 mm	Operating Weight	32.3 Tons
Width	3000 mm	Tube Cleaning Space	8500 mm
Height	4000 mm	Flooded Weight	0 Tons

Quick Checks

COP 0.71

Note:

This specification is for insulated m/c. For un-insulated m/c, the capacity and hot water flow shall be 95% and 105%

Hot water pr. drop does not include pr. drop in Control valve.

Fric.loss /pr. drops mentioned are for flowing liquid.

Version Number ProChill_LTHW_A1.4.

Figure G.2. Specifications for 2,288 MW absorption cooling machine

27-05-05 10:00 0232 4597790 FORM AS 004

0232 4597790

Hot Water Fired Machine

Technical specification for Vapour Absorption Chiller

Date: 26.May.05

THERMAX

Client:

Project:

Model

Model	LT 34 S		
Capacity	1496	±3%	kW
	425.7	±3%	TR

Tube Material

Evaporator	Copper
Absorber	Copper
Condensor	Copper

Chilled Water

Temperature	In 12 / Out 7	°C
Flow	257.6	m³/hr
Fouling Factor	0.00005	(metric)
Glycol	0	%
Fric.Loss/Pr.Drop	7.3 / 9.1	mLC
Passes (Evap)	4	
Conn.	200	NB(mm)

Cooling Water

Temperature	In 29.4 / Out 36.1	°C
Flow	469	m³/hr
Fouling Factor	0.00005	(metric)
Glycol	0	%
Fric.Loss/Pr.Drop	4.2 / 9	mLC
Passes (Abso/Cond)	2 / 1	
Conn.	250	NB(mm)

Power Supply

Supply Power	415V±10%, 50Hz±5%, 3Ph	
Power Consumption	8.7	KVA
Abso Pump Rating	3	kW
Refr Pump Rating	0.3	kW
Vac Pump Rating	0.75	kW

Hot Water

Temperature	In 110 / Out 95	°C
Flow	128	±3% m³/hr
Glycol	0	%
Fric.Loss/Pr.Drop	4.9 / 4.9	mLC
Passes (Gen)	4	
Conn.	200	NB(mm)

Dimensions

Length	5500	mm	Operating Weight	19.4	Tons
Width	2500	mm	Tube Cleaning Space	4100	mm
Height	3600	mm	Flooded Weight	27.5	Tons

Quick Checks

COP 0.7

Note:

This specification is for insulated m/c. For un-insulated m/c, the capacity and hot water flow shall be 95% and 105%

Hot water pr. drop does not include pr. drop in Control valve.

Fric.loss /pr. drops mentioned are for flowing liquid.

Version Number: ProChill_LTHW_A1.4

Figure G.3. Specifications for 1,496 MW absorption cooling machine

27-05-05 09:59 0232 4597790 FORM AS 002
0232 4597790

ŞİRKETLER GRUBU
GROUP OF COMPANIES

ABSORBSİYONLU CHILLER GRUBU

Ürün Adı	Adedi	Birim Fiyatı	Tutar	Para Birimi
LT 14 S Soğutma Kapasitesi : 1200 kW Chiller Devresi : 12 / 7°C Soğutma Kulesi Devresi 29,7 / 36,7°C Sıcak Su Devresi : 95 / 110°C Sıcak Su Debisi : 102 m3/h Boyutlar: 5200x2500x3400 mm Boş Ağırlığı: 16,5 ton Dolu Ağırlığı : 22 ton	1	153.600,00	153.600,00	EURO

TOPLAM BEDEL	153.600,00	EURO

Ürün Adı	Adedi	Birim Fiyatı	Tutar	Para Birimi
LT 34 S Soğutma Kapasitesi : 1496 kW Chiller Devresi : 12 / 7°C Soğutma Kulesi Devresi 29,4 / 36,1°C Sıcak Su Devresi : 95 / 110°C Sıcak Su Debisi : 128 m3/h Boyutlar: 5500x2500x3600 mm Boş Ağırlığı: 19,4 ton Dolu Ağırlığı : 27,5 ton	1	178.900,00	178.900,00	EURO

TOPLAM BEDEL	178.900,00	EURO

Ürün Adı	Adedi	Birim Fiyatı	Tutar	Para Birimi
LT 14 S Soğutma Kapasitesi : 2288 kW Chiller Devresi : 12 / 7°C Soğutma Kulesi Devresi 29,4 / 36,7°C Sıcak Su Devresi : 95 / 110°C Sıcak Su Debisi : 194 m3/h Boyutlar: 8200x3000x4000 mm Boş Ağırlığı: 32,3 ton Dolu Ağırlığı : 41 ton	1	267.150,00	267.150,00	EURO

TOPLAM BEDEL	267.150,00	EURO

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Figure G.4. Price offer and specifications for 2,288 MW and 1,496 MW absorption cooling machines (Third table in this figure shows LT-52S, not LT-14S)