DISTRICT HEATING ENERGY ANALYSIS

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ABSTRACT

An energy analysis is made of the use of geothermal energy for district heating. For this purpose, an assumed model based on real district heating systems in Iceland is taken as an example. Thus the economy of using geothermal energy for district heating with or without the combination of fossil fuel energy is investigated.

The results of the analysis suggest that the geothermal energy is well suited for bearing the basic load during the whole heating period, and that the most reasonable arrangements of geothermal energy and fossil fuel energy (fuel oil) are as follows:

When the geothermal field is far away from the heating market, 18 km in this report, and using price relations in Iceland in July 1984 the geothermal energy should supply between 70 and 82% of the peak-load demand which corresponds to 94 to 98% of the annual energy demand. If, however, the geothermal field is located very close to or inside the city boundaries the geothermal energy should supply at least 83 to 89% of the peak power demand, which corresponds to 98 to 99% of the annual energy demand.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Scope of work

The author was awarded an United Nations University Fellowship to attend the 1984 UNU Geothermal Training Programme at the National Energy Authority in Iceland. The training started with an introductory lecture course lasting for 4 weeks through which the author got a general background concerning most wide aspects of geothermal energy. These included geothermal energy and its development around the world, geology, geophysics, geochemistry, borehole geology, borehole geophysics, drilling and completion, reservoir engineering and the utilization of geothermal resources.

Following the introductory lectures, the author received some specialized lectures about geothermal utilization. These included geothermal water chemistry, sampling, collection, disposal, corrosion, deposition, deep-well pumps, automatic control of geothermal district heating systems and the Icelandic experience in geothermal district heating design and utilization.

After that the author went on an excursion to investigate the main geothermal fields in Iceland from 11th to 20th July 1984.

The second stage of the training lasted 4 weeks and was mainly devoted to a feasibility study of geothermal district heating. This report is an outcome of the research project carried out mainly during the last three months of the training.

In this training programme the author has got great fruits in many aspects. It is the author's belief that this training will be valuable after the author returns to China.

1.2 Geothermal utilization

Geothermal energy has been utilized for several decades in some countries. Some high-temperature geothermal energy can be used for production of electricity, but it is evident that much of the world's overall geothermal resources appear better suited for direct application than electrical production. This is due to fundamental physical considerations derived from the Second Law of Thermodynamics. The efficiency of resource utilization is usually above 80% in direct applications and is only 15% or so in production of electricity. The direct use of geothermal energy for space and domestic water heating (<120, >80°C) has been successful in many countries which possess the geothermal energy, not least in Iceland. Geothermal district heating has become widespread in Iceland and, at end of 1983, about 80% of the space heating requirement were met with geothermal energy. The annual saving in imported oil due to the use of geothermal energy amounts to US $ 560 per capita (Palmason, et al., 1983).

Geothermal energy is not always suitable and economically feasible for district heating at all localities. This is because of the characteristics of the geothermal energy source, such as limited resources, the temperature and flow rate, the location of the geothermal reservoir, and the geothermal fluid composition. So, in order to determine how to use the geothermal energy most economically, an energy analysis for the whole system is both important and necessary.

A geothermal district heating system will generally have the same basic components as other conventional district heating systems. It is practical to divide the construction of the geothermal district heating system into four main parts, which break down as follows:

Heat production; 1) Exploration and assessment of the geothermal field; 2) Drilling and borehole completion; 3) Collecting pipelines and degassing.

Transportation; 1) Pumping station and eventual heat exchangers; 2) Supply pipelines.

Potential peak power station; 1) Oil-fired boiler or other power boosting equipment.

Distribution system; 1) Distribution pumping station and storage tanks; 2) Street networks; 3) Service branches; 4) Consumer connections.

Figure 1 schematically illustrates a geothermal district heating system.

2 DESCRIPTION OF THE TASK

2.1 General

Most geothermal district heating systems in Iceland rely entirely on geothermal energy sources. In some systems, however, additional energy from heavy-fuel oil-fired boilers or heat pumps (electricity) has to be employed for reserve or peak energy purposes. This may be due to insufficient hot water resources in the geothermal field or due to the expense of drilling extra boreholes to serve the peak-load. The energy price ($/kWh) of a new borehole is quite high as the annual energy production from the peak-load borehole is very little. This economic evaluation may change if the investment is evaluated on a long-term basis, i.e. on the assumption that the energy demand will increase with subsequent decrease in the unit-price of energy for the new boreholes.

This study is carried out in order to examine the economy of district heating schemes and to determine the best combination of geothermal and fossil fuel energy.

To simplify the work, the following model is employed as a frame for the study. Although this study is limited to the specifications of the model, it is hoped that the methods described can be used for evaluation of other systems, e.g. combination of coal/oil, geothermal/coal etc.

This is an entirely academic exercise but supported by figures from real district heating systems, typical meteorological data for Iceland, engineering cost figures etc. The assumptions are stated clearly below and in the appendices and should be examined carefully before attempting to extend the results of this study to other applications.

2.2 Model description

It is assumed that the following district heating system exists:

A district heating company supplies 375 l/s of 85°C hot water to consumers from a geothermal field. Average flow rate from each borehole is 35 l/s. Cooling of hot water in main transmission pipelines is 2°C and in the distribution network 3°C (total heat loss is approximately 12% of max. peak power). It is intended to extend the distribution of hot water to the nearby town, and an increase is forecast in the present market. The district heating company must investigate how to meet this increase in energy demand. The total volume of houses served in the existing and new district heating systems will be 5 million cubic metres, and the average volume of buildings is 600 m^3. Design criteria for house heating systems (radiators etc.) is 80°C supply, 40°C return, -15°C outside temperature and 20°C room temperature. The geothermal water is piped directly to the house heating systems (radiators) and to domestic appliances (tap water).

In order to estimate the necessary hot water flow rate to each house and the system as a whole it is assumed that the "average house" has the following building parameters (Icelandic State Housing Agency, see Appendix I):

$\alpha = 2.36$; $\beta = 3.17$; $Kl = 2.36+3.17/(20-Tg)$ W/m^3;
$m = 396.8$ $KJ/m^3{}^\circ C$; $a = 0.2177(Ko+Kl)$; $b = Kl/(Ko+Kl)$

Kl is the overall heat transfer coefficient of the building, but other parameters are explained in Appendix I.

3 ANALYSIS OF ENERGY REQUIREMENT

3.1 Meteorological data and degree days

As known, the energy consumption for space heating is a function of climatic conditions as well as the type of building.

Table 1 and Fig. 2 show a typical distribution of numbers of days in which the daily mean temperature is below 20°C (Data for Akureyri, a town in northern Iceland. Meteorological data was obetained from the Icelandic Weather Bureau). Fig. 3 shows the number of degree days for the same. According to a method described in the ASHRAE handbook (ASHRAE, 1981), the annual heat load is equal to

$$DDT \cdot HL \cdot 24/\Delta T \quad KJ/yr.$$

where, DDT = annual number of degree days; HL = heat loss KJ/hr; ΔT = difference between inside and outside temperature, °C.

Since the degree days were obtained from annual or periodical meteorological data, there may be some deviations which can affect the maximum heat load evaluation.

3.2 System design temperature

The so called system design temperature is an important parameter for determination of the heat load. If the design temperature is too high when used in calculation of the heat demand, the room temperature will be lower than the permitted lowest room temperature in the most severe cold waves. However, if it is too low, the heat demand will be over estimated which will result in over-investment in energy supplies and distribution. Therefore, the system design temperature is not customarily the lowest climatic temperature of the record.

For determination of the system design temperature, it is necessary to study the available weather data for the area and to estimate the effects of the worst cold waves on the inside temperature of buildings. A cold wave is defined as a period of at least two days for which the outside daily mean temperature is below the system design temperature. The system design temperature must be selected low enough, so that the maximum cooling of buildings during the most severe cold wave to be expected will not bring the inside temperature down below a predetermined value. This minimum inside temperature for which district heating systems in Iceland are designed is often taken as 17 to 18°C (Karlsson, 1982).

Table 2 shows information that was obtained from severe cold waves between 1965 to 1979 (data from Akureyri). Based on these meteorological data the system design temperature can be defined as -13°C. At this temperature the inside temperature drop is 2 to 3°C, so the room temperature can be maintained at 17 to 18°C.

3.3 Parameters in district heating systems

When using geothermal energy for district heating, the supply water temperature is usually lower than 100°C. Normally the maximum temperature at the inlet of a radiator is 70 to 90°C. The temperature drop in house systems is about 40°C which is much greater than in other conventional district heating systems.

Due to the different extent of insulation and other parameters for buildings, each house has it's own heat transfer coefficient. But for a district heating study like this, an average coefficient for the whole system may be used. In this report the overall heat transfer coefficient is defined as (see Appendix I):

$$Kl = 2.36 + 3.17/(20-Tg)$$

This value is obtainted for a typical one storey house.

Based on DIN 4703 and the equation for steady state of heat loss of a building the following relationships apply (Karlsson, 1982):

$$\frac{m}{m_o} \cdot \frac{Tf - Tb}{Tf_o - Tb_o} = \frac{K1}{K_o} \cdot \frac{Ti - Tg}{Ti - Tg_o} \qquad (1)$$

$$\text{and } \theta = \frac{Tf - Tb}{\ln[(Tf-Ti)/(Tb-Ti)]}$$

$$= \theta_o\left(\frac{K1}{Ko} \cdot \frac{Ti-Tg}{Ti-Tg_o}\right)^{3/4} \qquad (2)$$

where,

θ = logarithmic mean temperature difference; Ti = inside or room temperatureequal to 20°C; Tg = outside temperature; m = mass flow rate for a typical house; Tf = supply water temperature to a house; Tb = return water temperature from a house; Ti_o, Tg_o, m_o, θ_o are values for standard conditions.

Fig. 4 and Fig. 5 show the function relations between Tf, Tb, and Tg at a fixed mass flow rate for a typical house. Since these curves are obtained for a typical house, correction is necessary when the building parameters change. The figures can be corrected by using Fig. 6.

3.4 Power demand

As the previous discussion shows, the space heating power demand is closely related to the outside air temperature distribution over a year (or a season) and the system design temperature as well as other elements (see further Appendix VII 2).

The annual hot tap water requirement is on the other hand independent of the seasons and outside temperature. It is assumed to be a constant percentage of the total heat load.

The heat loss in the whole system is a function of temperature difference between room temperature and air temperature, if other conditions are the same, e.g. insulation of buildings, pipe material etc. (see further Appendix VII 1).

The maximum power demand (100 percent) occurs when the outside temperature is low and equal to the system design temperature. Following the outside temperature increase, the power demand decreases with a corresponding function relation. A typical power demand curve based on the previously described meteorological data (see 3.1) is shown in Fig. 7.

The power demand duration curve shows the following: The area under this duration curve is the total energy consumption of a whole year. For the same peak power demand, the lower the yearly mean temperature, the longer the time of space heating; thus better economy of the overall heating system can be expected.

Due to the position of Iceland and its climatic characteristics, the geothermal district heating systems can operate very economically.

There are different ways to determine the heat demand in a specific system:

From equations (1) and (2), at $Tg = -13°C$, and $Tf = 80°C$, it can be calculated that the required maximum flow rate to the average house is $m = 0.061$ l/s and return water temperature is 38°C (Figs. 4 and 5). According to experience in Iceland, the hot tap water is estimated 15% of the total demand. The total maximum required hot water flow rate for the whole district heating system, i.e. 5·10E6/600 = 8333 houses + 15%, is thus $M = 598$ l/s (tap water is 90 l/s).

The peak power demand may be calculated by the formula

$$P = M \cdot 4.186 \cdot \Delta T \cdot 10E\text{-}3 \text{ (MW)}. \qquad (3)$$

Therefore, the peak power demand at the consumers in the model is 105 MW ($\Delta T = 80-38 = 42°C$). The peak power demand at the geothermal field is 118 MW considering the heat loss (temperature drop 5°C).

If another method, which is mentioned in "Geothermal District Heating - The Iceland Experience" (Karlsson, 1982) is used, and assuming that the mixed houses' heat requirement is 21 W pr. cubic metre (for buildings with direct tap water connection), the maximum hourly demand factor 15% and heat loss factor 10%, then the total peak load at the geothermal field is P = 131 MW.

The deviation between the two methods is 10%. This could be explained by the average heat transfer coefficient being estimated higher than the real condition. It is concluded that the peak power demand as estimated from the first method is adequate for practical requirements.

The tap water requirement may be estimated according to a method described in "Geothermal District Heating - The Iceland Experience" (Karlsson, 1982) as 0.23 l/s per 100 persons. The average building volume for each person may be taken as 127 m^3/person, data from Akranes (Karlsson, 1982). Thus the total tap water quantity is

$$\left[5\cdot 10E6/(127\cdot 100)\right]\cdot 0.23 = 90 \text{ l/s}.$$

This number corresponds to the above estimated percentage.

3.5 Energy demand

The power demand or duration curve defined in the last section (Fig. 7) displays the number of days in a year that a certain power demand exists. The area under the duration curve represents the total annual energy requirement, while the values on the vertical axis express the power required from the heat source (geothermal, oil etc.).

In order to obtain the energy from a heat source which is employed all year round the power duration curve is integrated horizontally i.e.

$$\% \text{ Energy} = \int_0^y T(p)\,dp \qquad y = \% \text{ power demand}$$

This energy curve, which is usually presented as a percentage power demand versus percentage energy, has been plotted in Fig. 8 as curve A. This energy curve shows that for the data in our example, a base heat source, which has a capacity equal to 60% of peak power demand, will supply 88% of the annual energy reguirement. If the remaining 40% of the power are supplied from a peak-load boiler, this only provides 12% of the energy. Furthermore, the 60% base heat source fulfills the energy requirement 61% of the time, whereas the peak load boiler is only used 39% of the time each year.

The combination of different heat sources just described can be termed as "parallel operation", but another combination is defined as "alternative operation". This is the case when one heat source is employed for a part of the year, (usually low demand season) and is replaced by a different heat source for the remainder of the year (high demand season). In order to obtain the percentage energy /percentage power curve as before the power duration curve is integrated vertically or

$$\%\ \text{Energy} = -\int_{100\%}^{x\%} P(t)\,dt$$

$\%$ Power = $P(to)$,

$x\% = 100\% - to$; x is operating time.

This is plotted in Fig. 8 as curve B. Now it may be observed that the 60% base power represents only 53% of the annual energy and the peak-load boiler now provides 47% of the same. The alternative operation is especially suitable where inexpensive fuel, e.g. gas, is available for heating during off-load seasons. This can also apply to a heat-pump operation which employs air or water as the heat source which is inefficient during cold periods.

4 FEASIBILITY STUDY

4.1 Capacity of the present geothermal supply (model)

Due to the limitations of temperature and flow rate of the present system (see Chapter 2), the power available from the geothermal field is not sufficient for the whole space heating period. Therefore, it is necessary to determine the minimum outside temperature at which the system is inadequate and the heating company in the model must take other actions to meet the power requirement. According to the parameters of the system, the present flow rate of 375 l/s, of which 90 l/s are required for tap water, will only be able to maintain the minimum room temperature in the extended district heating system in relatively mild weather. The available flow rate to the "average house" is only 0.0342 l/s instead of 0.061 l/s. From Fig. 4 and 5, it may be derived that this reduced flow rate will only suffice if the outside temperature is -2°C or higher.

This means that some auxiliary heat sources must be employed in order to keep the heat quantity balance, when the outside temperature is below this temperature.

From Fig. 7 and Fig. 8 we can derive that the available power of the present system is about 64% of the maximum power demand of the extended system, Fig. 9, and the available energy is about 90% of the total energy demand. The number of days of a year, when the outside temperature is lower than -2°C is shown in Table 4.

4.2 Possible solutions

4.2.1 Entirely geothermal energy

If the total energy demandin the model has to be met entirely with geothermal energy, new boreholes must be drilled.

The number of boreholes can be estimated from P/p, where P is equal to the total power demand, or total flow rate, and p is the average power obtained from each borehole or average flow rate from each borehole.

If the average flow rate from each borehole is 35 l/s and the maximum required flow rate in the extended district heating system is 598 l/s, 17 boreholes will be required. In the present system 375/35 = 11 boreholes are employed. These 11 existing boreholes cover 64.7% of the total power demand of the extended system. Thus 6 new boreholes are needed for the full capacity of the present and new systems.

Two locations of the geothermal field will be considered:

Case A: The geothermal field is located outside the city boundaries as far as 18 km.

Case B: All of the boreholes are located inside the city boundaries.

In order to evaluate the economy of the different energy supply schemes it is necessary to calculate the cost of one energy unit or cost per kWh.

For the geothermal alternative, the main cost lies in the boreholes, and in the case of the distant geothermal field (case A), the main transmission pipelines. In this report it is assumed that one 35 l/s borehole has an annual cost of US$ 69,300, when the cost of the boreholes is depreciated in 12 years with 8% annual rate of interest (see Appendix II). This represents an average price of boreholes in low temperature geothermal fields in Iceland. It is further assumed that 3 of each 4 boreholes are successful. Included in the above price are down-well pumps and wellhead equipment.

Boreholes in geothermal fields are connected to a collection pipe network which carry the geothermal fluid to degassing stations, where dissolved gases are separated from the water. The annual cost of collection pipelines is estimated from existing collection pipeline systems and is taken as US$ 3,000 per borehole, when the cost of the pipeline system is depreciated in 20 years with 8% annual rate of interest (Appendix II).

The cost of transmisson pipelines is high and depends very much on the material and arrangement of the pipe (Bjornsson, 1980). The least expensive transmission pipeline is an asbestos cement pipe covered with earth and turf (peat). This may be partly insulated with rockwool, which reduces the otherwise high heat loss by up to 50% (Bjornsson, 1980). The most expensive pipeline is a steel pipe insulated with rockwool. The pipe is placed either in a concrete culvert or, which is more common for very long single transmission pipes, on concrete supports on the ground. In the latter case, the pipe and insulation is clad with aluminium sheeting.

In this report, it is assumed that the main transmission pipe between the geothermal field and the city distribution network is a single pipe of the last mentioned type. A comprehensive study of the cost of such pipelines has been carried out (VGK Consultants, 1982 and 1983), and the hot water transport cost is thus estimated at 3.3 mills/kWh (when $\Delta t=40°C$) for an 18 km long transmission pipeline system of fully utilized 600 l/s capacity. Included in this cost is the capital cost of the pipeline, pumping station, pump running cost and maintainance (Appendix III).

It is now possible to calculate the cost of energy obtained from each borehole. As mentioned before, the cost of the average borehole is more or less fixed, being the cost of the borehole itself, pump and wellhead equipment and collection pipelines. The annual energy that the borehole supplies is the multiple of its power and the annual operating hours. From the shape of the power demand curve, Fig. 7, it may be seen that the higher the power demand, the fewer the operating hours. Borehole designated number one has the longest annual operating time, borehole number two somewhat shorter etc. As the cost of each borehole is fixed the incremental energy cost, or energy cost per borehole, increases as the operating hours become fewer. The result of the incremental energy cost calculation is plotted for cases A and B in Fig. 10. It should be noted that this energy cost is the cost of energy at the connection to the distribution network.

The cost curves show a slight increase with increasing power demand at first, but the cost rises sharply when the power demand exceeds 60 to 70% of the maximum. The geothermal energy is very inexpensive compared to other energy sources when operation time is long (3000 hours or more), or only 2 to 4 mills/kWh for an in-city borehole and 4 to 9 mills/kWh for an out-of-city borehole. However, when operating hours are fewer, e.g. 550 annual hours, corresponding to 88% of the peak power demand, the price is 22 mills/kWh for an in-city borehole and 48 mills/kWh for an out-of-city borehole (Appendix VI), thus being higher than price of energy from an oil-fired plant (case C, see next section).

4.2.2 Partly geothermal, partly fossil fuel energy

In many geothermal district heating systems it has been necessary, due to limited geothermal resources or cost of drilling new boreholes, to supplement the geothermal energy with fossil fuel energy. Oil-fired boilers are used in Iceland for this purpose and it is the intention in this section to examine how a peak-load boiler plant may best be combined with the geothermal source.

Two arrangements of connecting the peak-load boiler to the geothermal district heating system will be considered. The first alternative is to collect return water from the district heating network and direct it to the peak-load boiler, heat it up and mix it with the supply water from the geothermal field (see Fig. 11 a).

The supply temperature to the consumers is then determined from the equation

$$Tf = \left[(Tfgeo \cdot Mgeo + TB \cdot MB)/Mtotal\right] - \text{temp. drop} \qquad (4)$$

and the heating in the peak-power plant is

T = Power from oil / $MB \cdot Cp = TB - (Tb - \text{temp. drop})$ (5)

where TB is the temperature of the water leaving the peak-power plant and MB is the flow rate of the water through the same.

These equations, combined with equations 1 and 2 in Chapter 3 give the necessary power required from the oil-fired boiler as a function of the outside temperature Tg. The equations also determine the minimum mass flow rate through the boiler, in order that the temperature leaving the boiler, TB, is within reasonable limits, e.g. lower than 120°C.

The cost of operating a peak-power boiler plant is predominantly fuel cost, but capital cost and maintainance must also be included. In the return-loop system, as indicated in Fig. 11a, the cost of the double distribution network has furthermore to be considered. The cost of single and double pipe networks has thus been examined (see App. IV).

The second alternative of connecting an oil-fired boiler to the geothermal distribution network is to use the boiler as a direct booster (see Fig. 11 b). The supply water is passed through the boiler, either partly or entirely and the temperature of the mixed streams leaving the boiler plant is determined from the outside temperature Tg, and available water flow rate Mgeo according to equations 1 and 2. This method is possible only if sufficient water quantity is available from the geothermal field so that the supply temperature can be kept lower than 100°C.

The economy of this method compared to alternative 1, i.e. the return-loop system, is better because:

1. By raising the supply temperature by 1°C, the return temperature can be lowered by 1°C, still maintaining the same radiator /room temperature difference. This means that the water flow rate can be kept lower than in alternative 1.

2. A double distribution network is not necessary.

The energy cost of the oil-fired boiler is plotted as case C in Fig. 10. This cost includes cost of heavy fuel oil and capital cost of the power plant as explained in Appendix V.

4.3 Economy of the different solutions

In order to evaluate the overall cost of energy from the different energy sources the accumulated energy cost is calculated and plotted in Fig. 12 (see also Appendix VI).

Curve A represents the previously described case A, i.e. entirely geothermal energy from an out-of-city geothermal field. The accumulated cost at connection to the distribution network is estimated to be 5.8 mills/kWh for 100% demand. On the same diagram, curves for peak-power plant of different capacity are plotted as the C-curves. C1 represents a case where 64% of the peak power demand is met with geothermal energy, i.e. the capacity of the present geothermal supply or 375 l/s, and the remaining 36% are met with an oil-fired boiler plant of 42 MW.

The overall energy cost of this alternative is quite high, or 6.2 mills/kWh. This means that it is not economical to meet the increased power demand of the extended district heating system entirely with an oil-fired power plant.

Curve C3 represents the energy cost if geothermal supply covers 82.4% of the peak power demand and oil-fired boiler 17.6%, or 21 MW. The overall energy cost at 100% demand will in this case be 5.4 mills/kWh or a little lower than the case of entirely geothermal. The critical ratio of geothermal to energy from oil is at 70% geothermal and 30% oil. This ratio leads to the same overall energy cost as entirely geothermal.

The conclusion which may be drawn from this is that the ratio should be between 70/30 and 82.4/17.6. Geothermal power should not be lower than 70% and not higher than 82.5%.

Curve B in Fig. 12 represents entirely in-city geothermal energy. The overall price of energy at 100% demand is 2.8 mills/kWh or only half the price of the out-of-city geothermal energy at connection to the distribution network. The critical ratio is now at 83% geothermal and 17% oil. The lowest price of energy is obtained if the geothermal covers 88.6% of the peak power demand and 11.4% is met with oil, or 13.5 MW.

4.4 Conclusions and discussion

The above results evidently show that the optimum peak power factor is not at 60% or so of the maximum power demand, as is common in other countries for coal/oil energy supplies. The optimum economic point, i.e. the optimum combination of geothermal and oil fuel energy,is at 70% or over of maximum power demand according to this energy analysis.

Why this is so can be explained by the fact that the fuel oil prices are higher and the geothermal energy sources less expensive in Iceland than elsewhere. For comparison the fuel oil cost is only 10 mills/kWh in U.S.A. while it is 30 mills/kWh in Iceland. Furthermore, in Iceland, the geothermal water temperature is often higher than 85°C and can be used directly without using heat exchangers. Also reinjenction wells are not required in low temperature geothermal fields in Iceland.

As explained before, the hitherto calculated energy price represents the cost of energy at the connection to the distribution network. In order to obtain the price to consumers one must add the cost of the distribution network, i.e. capital cost, maintainance etc. If this annually amounts to 10% of the initial investment, the distribution network cost is estimated at 4 (single) to 7 mills/kWh (double pipe network). Thus the energy price at consumers will be from 2.8 + 4 = 6.8 mills/kWh (in-city boreholes and single pipe network) to 5.4 + 5 = 10.4 mills/kWh (out-of-city boreholes + peak power plant and 30% double pipe network). For comparison the price of thermal energy to the consumers in the least expensive district heating systems in Iceland is between 7 and 10 mills/kWh based on 40°C cooling of the hot water in the house heating systems and prices in July 1984 (e.g. Selfoss, Husavik and Reykjavik). The energy price in the most expensive geothermal district heating system in Iceland is, however, up to 30 to 35 mills/kWh.

Where the situation in and around the geothermal field is difficult, e.g. due to salinity, the cost of the geothermal energy may be much higher than what is presented here. For example "doublets", i.e. production and reinjection wells which form a pair or a doublet, which are widely used in France, cost between 1.6 to 1.9 million US$. Necessary surface equipment, including titanium heat exchangers, pumps and distribution network cost between 2.8 and 3.9 million US$ (Barbier, 1984). The subsequent price of geothermal energy to the consumers (tax excluded) is about 20 mills/kWh. This, however, relatively low cost can be explained by the fact that the boreholes are placed in or very close to the distribution network. The price of the distribution network is also low due to the high energy density (30 - 70 MW/km^2) of the heated regions (Desurmont, 1983). In France the price of gas and coal lies in the same price range as the price of geothermal energy.

The results of this report indicate that even in Iceland the installation of oil-fired peak power plant or other peak load equipment is more economic than using geothermal energy entirely, if the geothermal supply temperature is lower than 85°C or so.

Moreover, this analysis just considers the different heat sources and compares these with each other. In practice, because the geothermal water temperature is limited, i.e. maximum 80°C at consumers for the model used in this report whereas the water temperature from an oil-fired boiler is not limited (up to say 120°C), the distribution network cost, when using peak power plant, is a little less than when using entirely geothermal energy. This is because it may be possible to use smaller dimensions in the piping system due to lower flow rates as a result of higher temperature levels.

Some calculated results for different models are shown in Table 5.

The different models are divided into two cases: In case I the geothermal energy covers 64.7% of the maximum power demand; oil-fired boilers cover 35.3% of the maximum power demand. In this case the peak power plant is used to heat supply water (Ia) or return water (Ib to Ie). The return water quantity is at different percentage of the total geothermal water flow rate, i.e. 17%, 30%, 41% and 76%. In case II the geothermal energy covers 82.4% of the peak power demand. The return water percentage rate is only used as the maximum 12% in case IIb.

Main conclusions drawn from the above analysis are as follows (see further Table 5):

i. Combination of partly geothermal energy and partly fuel oil gives a more favourable energy arrangement for district heating than entirely geothermal energy. The most reasonable peak-load factor is over 70% of the maximum power demand.

ii. Direct heating of supply water with a peak power plant is considered economic, if the supply water temperature can be controlled below a predefined maximum temperature for a given limited water flow rate.

iii. For return-loop systems (Fig. 11a) the less quantity of heated return water the higher the mixed water temperature, hence better economics of the whole system.

Because the analysis is based onthe limited conditions of the model, the above conclusions possess limitations. For example, if the geothermal fluid composition is such that the water is not suitable for direct use, or the geothermal field is far away from the city, the conclusions of this report may be different.

Furthermore, one case deserves to be mentioned i.e. in order to lower the peak-load, or to keep the hydraulic stability of the whole system, water storage tanks may be employed. In Iceland water storage tanks are commonly used as an auxiliary peak-demand adjusting equipment in geothermal district heating systems, especially in open (single) or partly single/partly double systems.

The above analysis does not consider water storage tanks because their effect is considered comparatively small in the total energy cost.

5 EPILOGUE

As explained in the introductory chapter of this report, the study presented here is primarily an academic exercise and should be regarded as such. However, in order to give the results of the report credibility, the cost figures used in the report have to the extent possible been based on real situations in Iceland. The resulting cost of energy thus reflects an average situation in Iceland when the geothermal energy can be readily harnessed.

The situation in and around the geothermal fields may be quite different in other countries, and this will demand more elaborate methods to utilize the heat than are applied in Iceland. One factor which may render the geothermal fluid unsuitable for direct use in district heating systems is its chemical composition especially with respect to corrosiveness and scale formation.

China has considerable geothermal resources which may be used directly in some places. In Beijing the geothermal fluid, which is 55 to 70°C hot, is however not well suited for direct use due to its chemical composition and other factors. In order to utilize the geothermal heat for domestic heating, the geothermal fluid has to be directed through heat exchangers where it heats up water for use in district heating systems. For the most economical use of the water, the district heating system will consist of a closed-loop network which is filled with treated fresh water, and top-up is only required to the extent of meeting normal water losses. The geothermal fluid will be reinjected after passing through the heat exchangers and this will maintain the stability of the geothermal reservoir and prevent subsidence and pollution around the geothermal field.

Presently there are district heating systems in China, e.g. Beijing, which utilize heat energy from combined electrical power/heat plants. Peak load heating is obtained from steam boiler plants. The results of this report show that geothermal energy is well suited for base heating. Although the temperature of the district heating water leaving the geothermal field is lower in China than in the larger district heating systems in Iceland, due to lower reservoir temperature of the geothermal fluid and the use of heat exchangers, the geothermal energy may cover a high proportion of the annual energy demand. This is well established elsewhere, e.g. in some geothermal district heating systems in France, where up to 80% of the annual energy is obtained from geothermal heat which, however, has only about 40% of the peak demand power. The power duration curve for northern China can be exemplified by the curve drawn in Fig. 13a. The heating season in northern China usually lasts 3-6 months and in Beijing the heating season is about 160 days (mean daily temperature below 10°C). This explains the shape of the power duration curve.

From the energy curve, Fig. 13b, it may be seen that a base heat source which has a capacity of 40% of peak load will cover 73% of the energy demand during the heating season.

Due to the relatively low temperature of the geothermal fluid in China, it will become necessary in cold weather to increase the temperature of the district heating water above the temperature which is obtainable from the geothermal well-head heat exchangers. A solution which may be employed in the regions of Beijing which have existing district heating, is to combine the geothermal system and the existing district heating system through heat exchangers. A possible connection arrangement is indicated schematically in Fig. 14.

As said previously existing district heating systems in Beijing now get their energy from combined electrical power/heat plants. Due to the short heating season and the fact that electrical power must be supplied all year round, there is a large thermal energy surplus which has to be transferred through cooling water from the power plants.

In order to save some of this energy, a new technique for heat storage may be applied. This is the seasonal storage of thermal energy in aquifers. Ground water, used as secondary cooling water, is heated by the primary cooling water. The secondary cooling water is reinjected into the ground during the summer and stored in aquifers for use in the heating season. The seasonal storage of thermal energy thus makes it possible to use the available heat more fully, whether it is for district heating or other utilization. A possible underground hot water reservoir system is indicated in Fig. 15 (Meyer and Hausz, 1978). In winter the valves 3 and 4 are open, but valves 1 and 2 closed; whereas the valves 3 and 4 are closed and valves 1 and 2 open in summer.

Thermal energy storage in aquifers is a very important aspect in energy management. It deserves full attention and should be closely examined.

ACKNOWLEDGEMENTS

The author wishes to express her special thanks to Dr. Oddur Bjornsson (Fjarhitun Consulting Engineers Ltd.) for his invaluable guidance and comments during the training course and the writing of this report. He offered a great assistance to the author in various aspects of this report.

The support of Dr. Ingvar. B. Fridleifsson Project Co-ordinator of the United Nations University in Reykjavik,is gratefully acknowledged, throughout the training period.

Thanks are expressed to Prof. Valdimar K. Jonsson for his valuable supervision and organization inthe engineering course.

Thanks are also expressed to Prof. Thorbjorn Karlsson for discussing the preliminary manuscript.

The author would also like to thank Maria J. Gunnarsdottir engineer at the National Energy Authority for her advice and information.

The author is indebted to Mr. Brynjolfur Eyjolfsson and Mr. Sigurjon Asbjornsson at the UNU Geothermal Training Programme at the National Energy Authority for their unlimited help in various aspects of this training.

Finally special thanks are expressed to everybody who has presented lectures or given assistance to the author during the whole training period.

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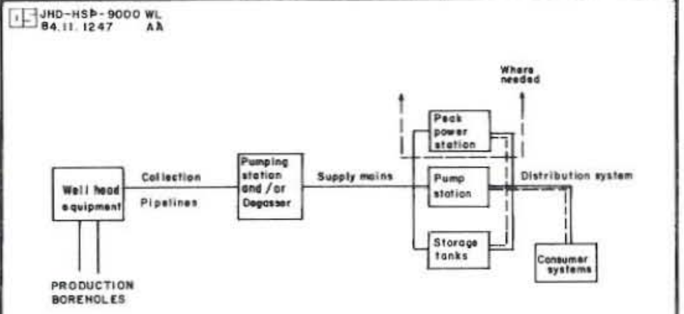

Fig. 1. Basic geothermal district heating system.

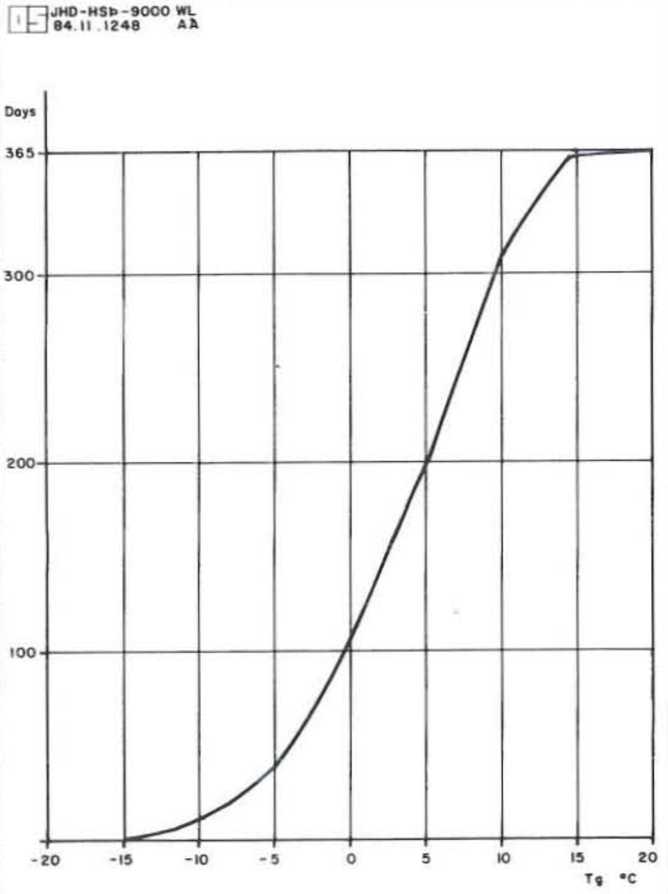

Fig. 2. Number of days with daily mean temperature lower than T+1.

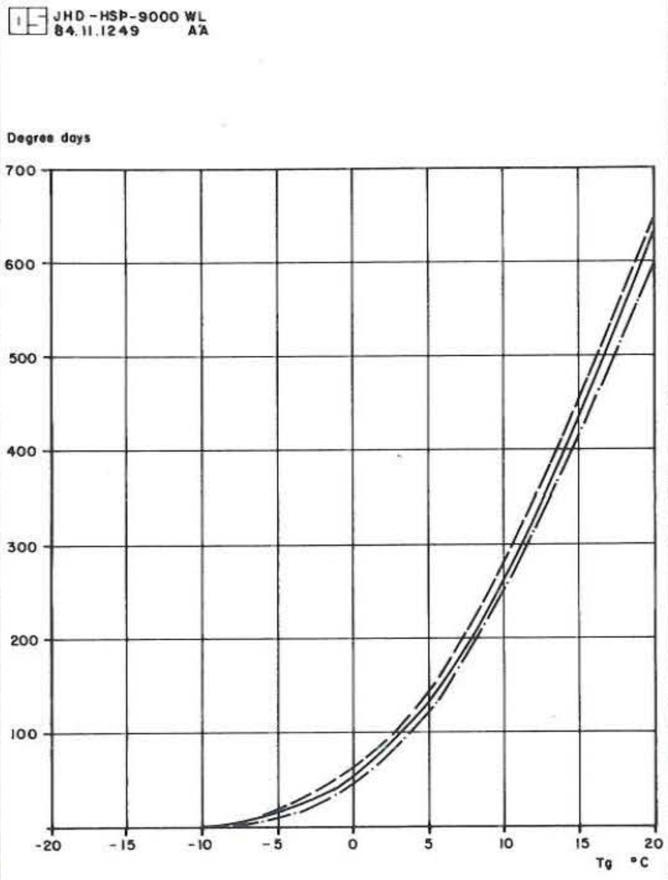

Fig. 3. Number of degree days per year colder than T+1.

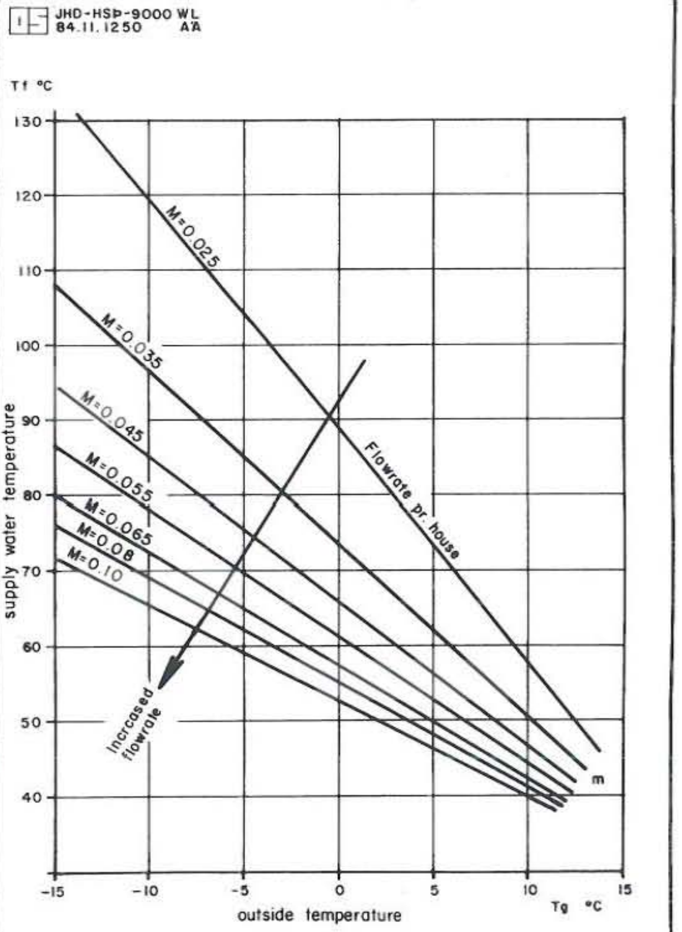

Fig. 4. Relation curves between supply water temperature and outside air temperature for an average house.

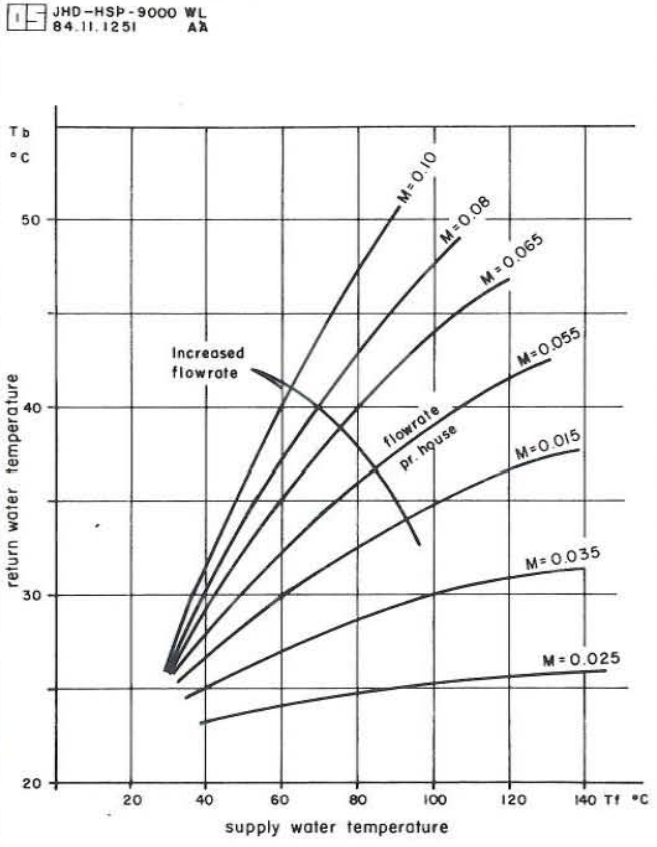

Fig. 5. Relation curves between temperature of supply and return water for an average house.

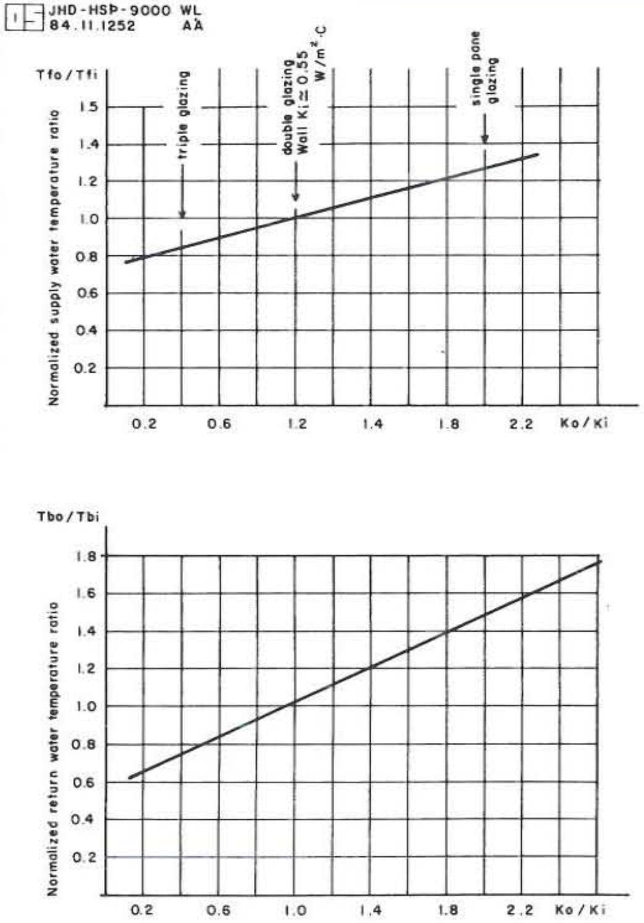

Fig. 6. Correction curve for supply water temperature (a) and for return water temperature (b).

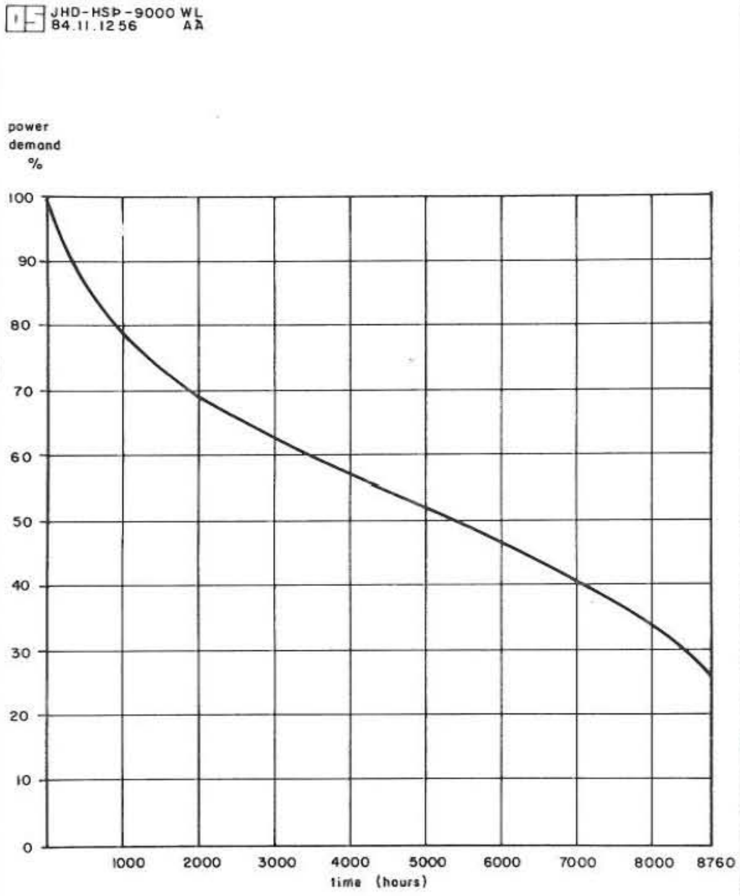

Fig. 7. Power demand duration curve.

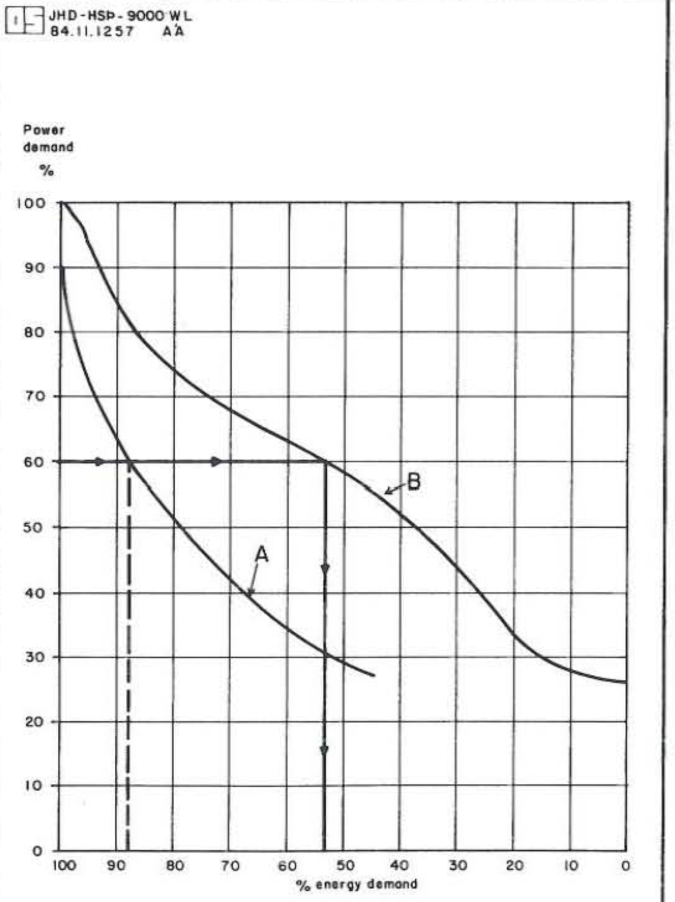

Fig. 8. Energy demand distribution curve.

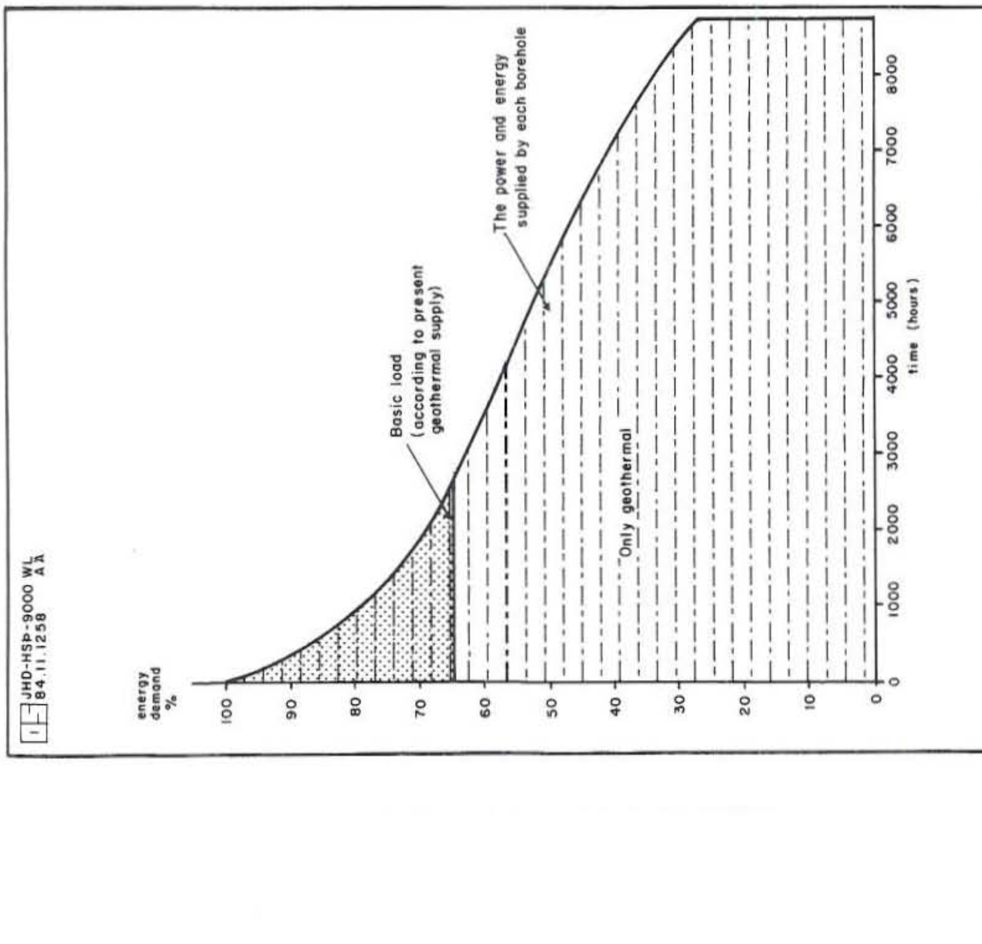

Fig. 9. Diagram of basic load and peak load.

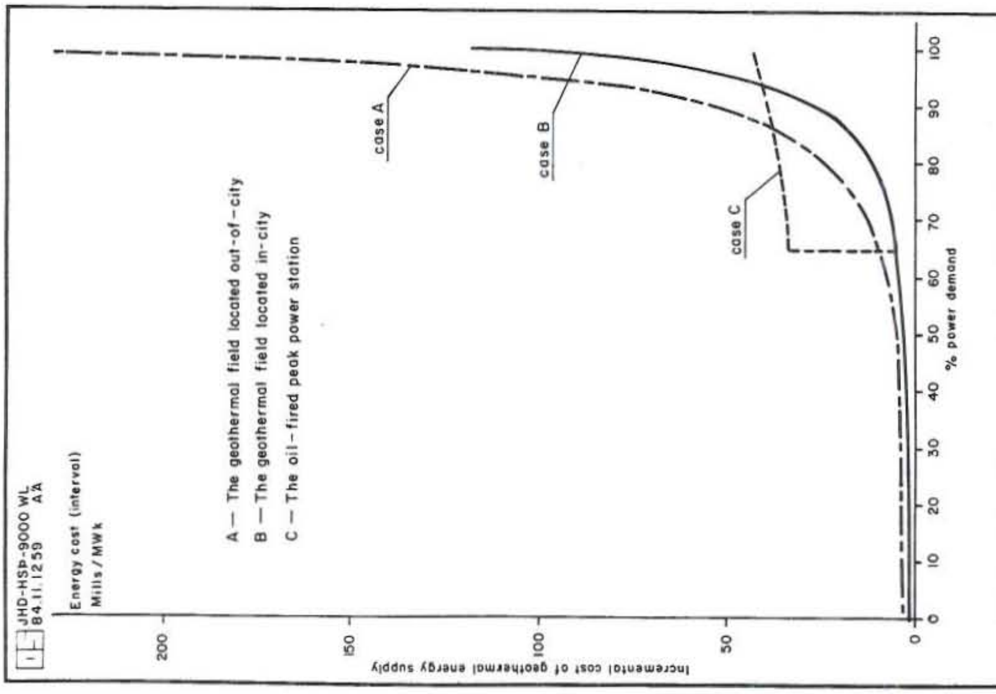

Fig. 10. Trends for energy cost of each borehole and an oil-fired peak power station.

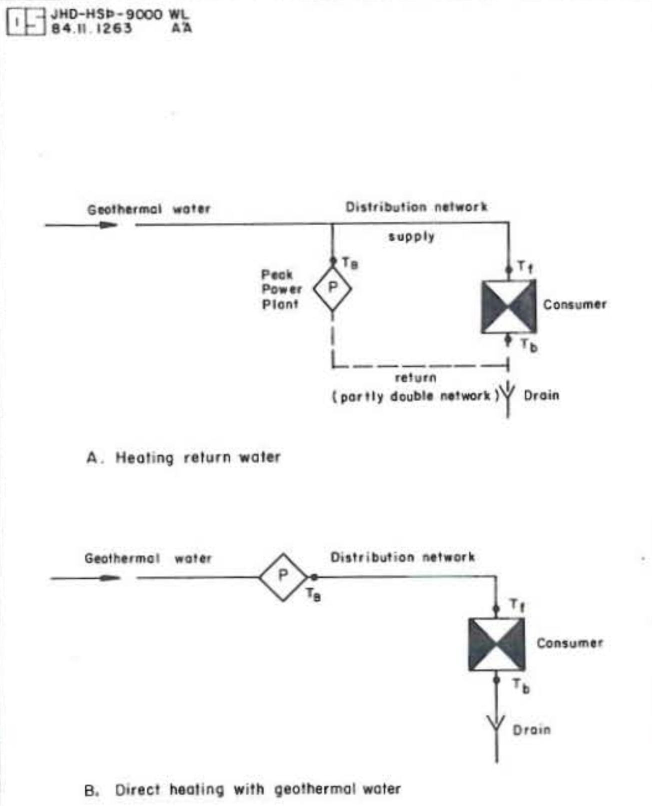

Fig. 11. Diagram of peak power plant location.

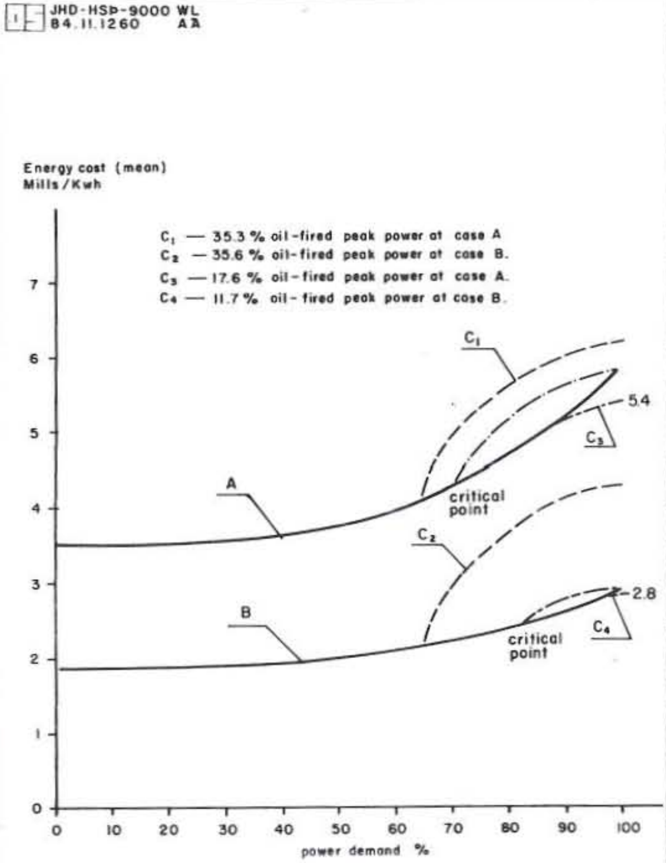

Fig. 12. Trends for accumulated mean energy cost of entirely geothermal and partly geothermal partly oil-fired peak power station.

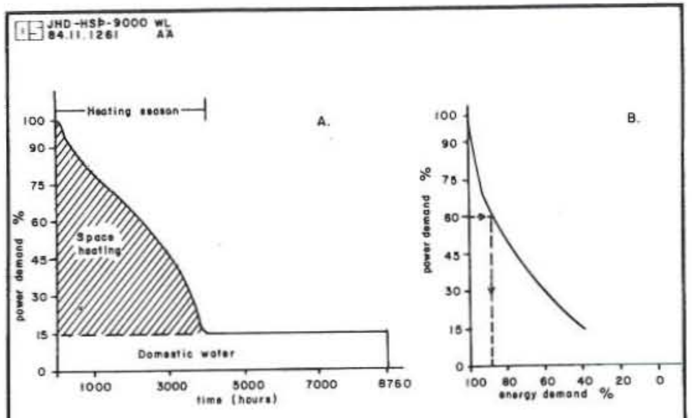

Fig. 13. Typical power demand duration curve and energy demand curve in northern China.

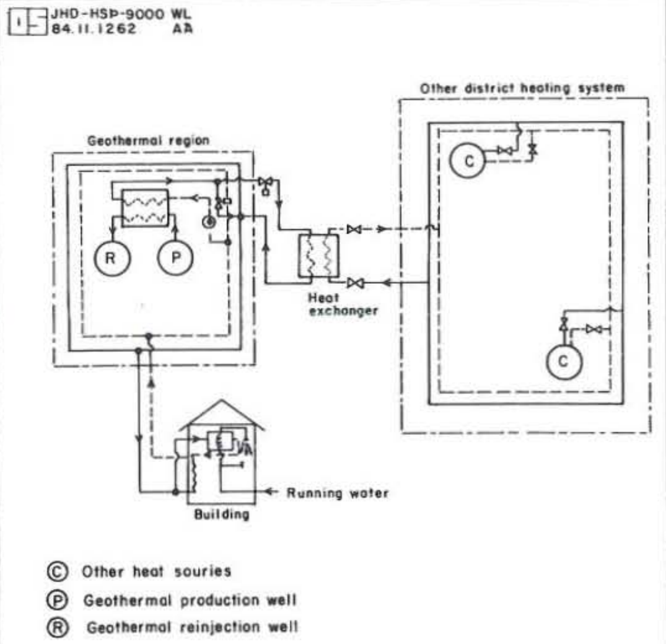

Fig. 14. Diagram of "doublet system" and possible connection between geothermal system and other district heating systems.

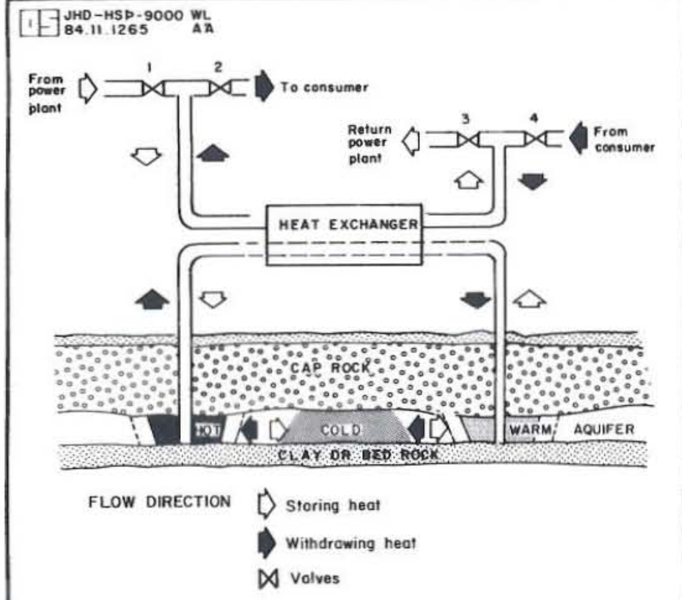

Fig. 15. Diagram of thermal energy storage in an aquifer.

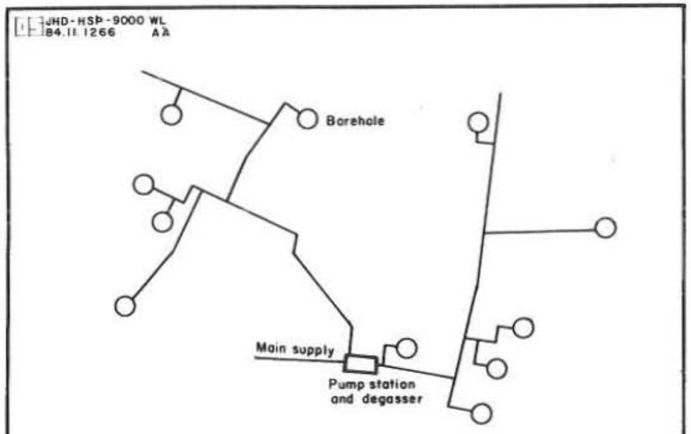

Fig. 16. Typical connection pipelines of boreholes.

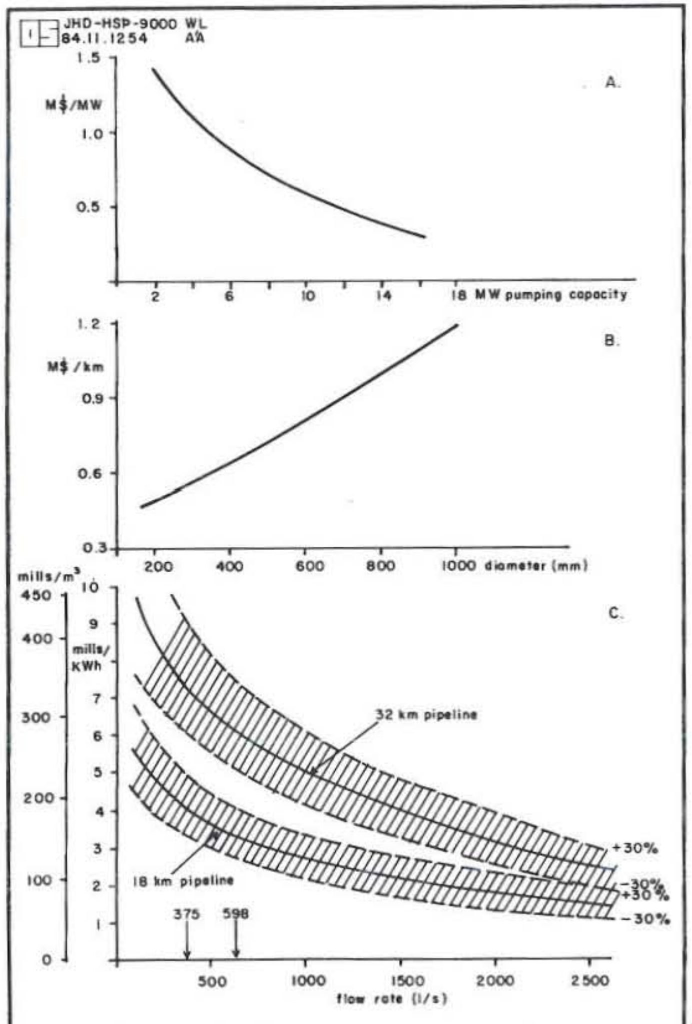

Fig. 17. Estimated hot-water transmission cost curves.

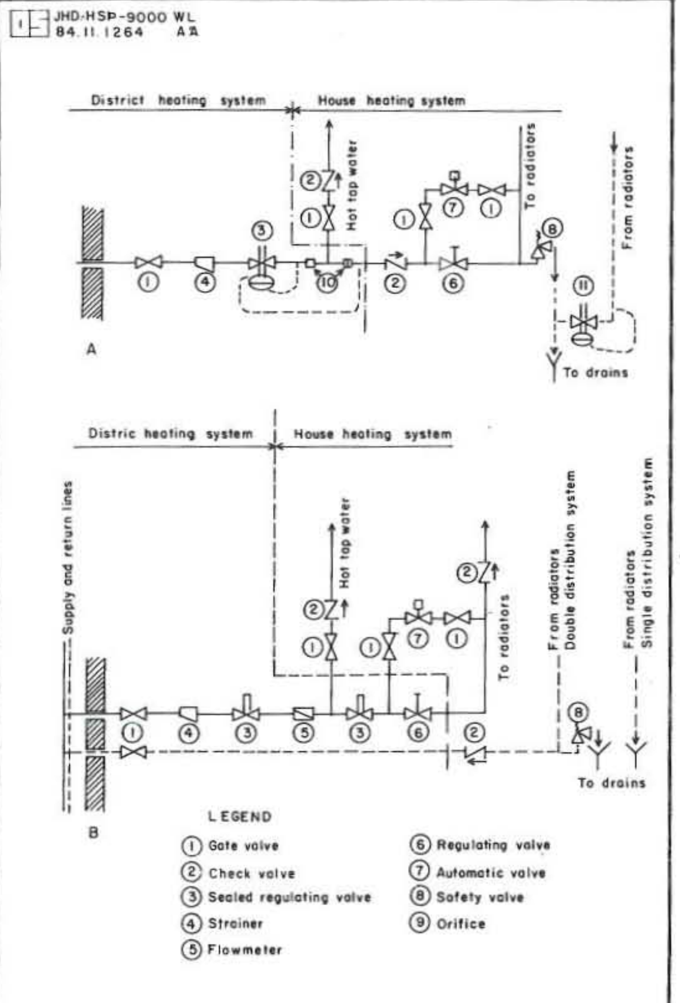

Fig. 18. Typical house connections.

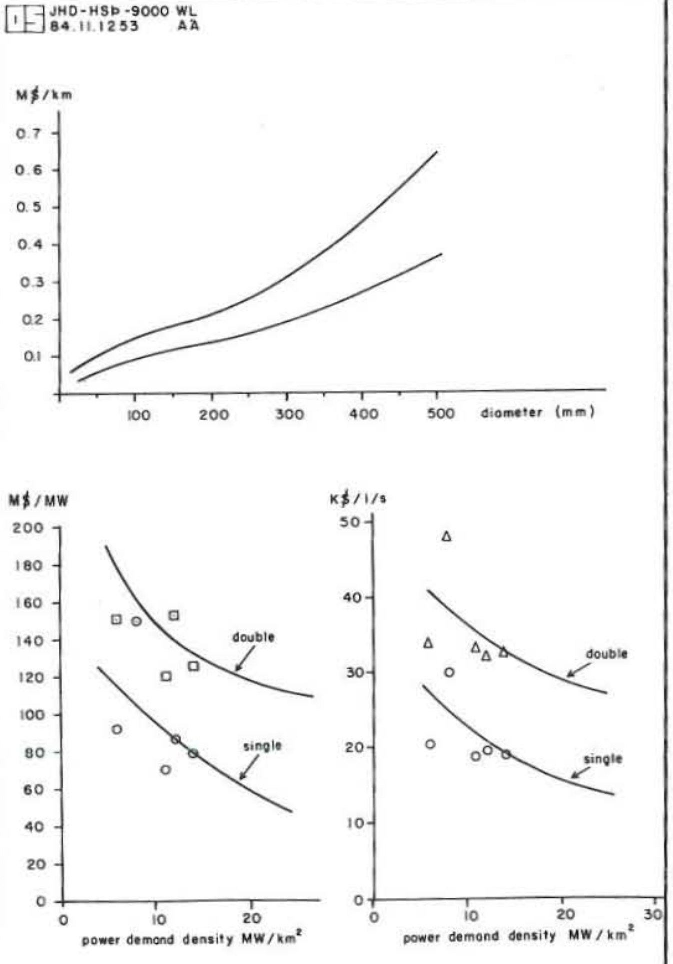

Fig. 19. Distribution network cost curves (estimated).

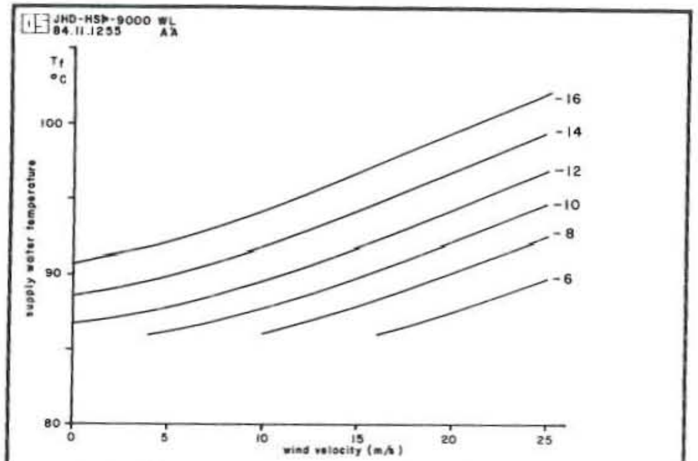

Fig. 20. Relation curves between wind velocity and supply water temperature at different design temperatures.

TABLE 1 Number of days and degree days having temperature lower than T+1

T to T+1 °C	N(T+1)	DD(T+1)
19 - 20	365	6171
18 - 19	365	5806
17 - 18	365	5441
16 - 17	365	5076
15 - 16	365	4711
14 - 15	364	4346
13 - 14	356	3982
12 - 13	345	3626
11 - 12	332	3281
10 - 11	318	2949
9 - 10	303	2631
8 - 9	282	2328
7 - 8	259	2046
6 - 7	238	1787
5 - 6	214	1549
4 - 5	203	1335
3 - 4	178	1132
2 - 3	161	954
1 - 2	141	793
0 - 1	122	652
-1 - 0	104	530
-2 - -1	88	426
-3 - -2	73	338
-4 - -3	61	265
-5 - -4	48	204
-6 - -5	40	156
-7 - -6	30	116
-8 - -7	22	86
-9 - -8	20	64
-10 - -9	16	44
-11 - -10	15	28
-12 - -11	8	13
-13 - -12	5	5

TABLE 2 Most severe cold waves occuring.

YEAR		FIRST DAY	DURATION	DEPTH OF COLD WAVE	TYPE OF COLD WAVE	TEMP. DROP	RESULT ROOM TEMP.
	Tg		To	Td		Tmin	20-Tmin
1965	-8	3	3	-6.57	REC	-3.22	16.78
1969	-9	65	6	-7.43	"	-3.80	16.20
1969	-10	65	6	-6.43	"	-3.28	16.72
1970	-11	7	3	-5.23	"	-2.56	17.44
1969	-12	31	2	-4.75	"	-2.12	17.88
1970	-13	8	2	-4.9	"	-2.19	17.81
1970	-14	8	2	-3.9	"	-1.74	18.26
1969	-15	65	5	-2.28	"	-1,16	18.84
1969	-16	67	3	-2.47	"	-1.20	18.80
1969	-8	36	4	-11.25	TRI	-4.04	15.96
1969	-9	30	4	-8.65	"	-3.10	16.90
1971	-10	3	3	-6.00	"	-1.93	18.07
1969	-11	65	6	-10.87	"	-4.37	15.63
1969	-12	65	6	-8.87	"	-3.56	16.35

REC : Rectangular cold wave.
$Tmin = bnTdn(1-\exp(-at_o))$.
TRI : Triangular cold wave.
$Tmin = 2nbnTdn(1-\ln(2n\exp(ant_o/2)-1)/ant_o)$

TABLE 3 Building parameters as a function of outside temperature (see Appendix I)

Tg	Kl	Ko	a	b
-8	2.473	2.361	1.053	0.512
-9	2.469	2.360	1.051	0.511
-10	2.466	2.359	1.050	0.511
-11	2.462	2.358	1.049	0.511
-12	2.459	2.357	1.048	0.510
-13	2.456	2.356	1.047	0.510
-14	2.453	2.356	1.047	0.510
-15	2.451	2.355	1.046	0.510
-16	2.448	2.355	1.045	0.509

$Kl = 2.316 + 3.17/(20-Tg)$ $Ko = 0.774 \cdot Kl^{1/4} \cdot (20-Tgo)^{1/4}$
$m = 396.8$ $a = 0.2177 \cdot Kl/b$
$b = Kl/(Kl+Ko)$.

TABLE 4 Number of the days when the outside temperature is lower than -2°C.

Daily mean temperature T - (T+1)	Degree days of temperature <T+1	Days of temperature <T+1	Number of days in each interval
-3 - -2	338	73	12
-4 - -3	265	61	13
-5 - -4	204	48	8
-6 - -5	156	40	10
-7 - -6	116	30	8
-8 - -7	86	22	2
-9 - -8	64	20	4
-10 - -9	44	16	1
-11 - -10	28	15	7
-11 - -11	13	8	3
-13 - -12	5	5	5

TABLE 5 Calculated results of different models.

CASE	Tg °C	Gg l/s	Gr l/s	Gs l/s	Tf °C	Tb °C	TB °C	ΔT °C	P MW	Investment K$ MP	Md	Mt
I. 64.7% geothermal, 35.3% oil-fired:												
a) direct heating supply water	-2	375	-	375	104,5	30,2	107,5	24,5	38,5	770	7,500	8,270
b) heating return water (17%)	-2	375	65	440	95,0	33,5	184,5	153,0	41,6	832	9,775	10,607
c) heating return water (30%)	-2	375	113	488	89,0	34,5	121,9	89,4	42,3	846	11,455	12,301
d) heating return water (41%)	-2	375	155	530	85,0	36,3	100,0	65,7	42,6	852	12,925	13,777
e) heating return water (76%)	-2	375	285	660	77,0	39,4	76,1	38,7	46,2	924	17,475	18,399
II. 82.4% geothermal, 17.6% oil-fired:												
a) direct heating supply water	-8	470	-	490	89,0	35,1	92,0	9,0	18,5	370	9,800	10,170
b) heating return water (12%)	-7	490	60	550	83,4	36,6	114,2	79,6	20,0	400	11,900	12,300

where Tg = outside temperature at which the peak power station starts (other data calculated at -13°C; Gg = geothermal water flowrate; Gr = return water flowrate; Gs = total supply flowrate; Tf water temperature at inlet of radiator; Tb = return water temperature; TB = outlet temperature at peak power station; ΔT = temperature rise at peak power station; P = peak power capacity; Mp = peak power station investment; Md = distribution pipeline investment; Mt = total investment on peak power station and distribution.

TABLE 6 Analysis of distribution network cost.

Typical region	Type of network	House volume $1000m^3$	Power demand MW	Flow rate l/s	Energy density MW/Km²	Network price M$	Estimated K$/MW	Cost K$/l/s
Ytri-Njardvik	SINGLE	254	4.8	24	8	0.723	150.6	30.1
	DOUBLE					(1.157	241.0	48.2)*
Grindavik	SINGLE	386	8.5	31	11	0.586	69.0	18.9
	DOUBLE					(1.026	120.7	33.1)*
Sandgerdi	SINGLE	221	4.7	21	6	0.43	91.5	20.5
	DOUBLE					(0.71	151.1	33.8)*
Keflavik	SINGLE	1052	25	99	14	1.80	72.0	18.2
	DOUBLE					(3.15	126.0	31.8)*
New suburb of Reykjavik	SINGLE	190	3.6	16	12	0.31	86.1	19.4
	DOUBLE					0.55	152.8	34.4

* Based on assumed double pipe system.

In this analysis it is assumed that the heat density is 10 MW/km², so the single system cost was taken as 20 K$/l/s, the double system cost was taken as 35 K$/l/s.

TABLE 7 Transmission pipeline heat loss.

Town	Diameter mm	Material	Length Km	Flow rate l/s	Heat flow GJ/yr	Heat loss %
Blonduos	200	a	13.5	28	11	29
Husavik	250	a	20.0	50	13.2	37
Vogar	150	sin	4	17	22.5	6
Hvammstangi	150	a	7.9	15.3	10.23	16
Bessast.hr.	150	a	3.7	5.3	7.56	16
Siglufjordur	200	ai	4.7	15-20	20.22	15
Hjaltadalur	125	sin	9.0	10	5.87	16
Njardvik	500	son	11.7	400	180.5	5

where, a = asbestos cement pipe without insulation; ai = asbestos cement pipe with insulation; sin = steel pipe laid in the ground insulation with polyurethane; son = steel pipe laid over the ground insulation with rook wool

APPENDIX I

Parameters of a Typical Building (The "average house")

Normalized values with respect to gross exterior wall area (133.6 m3)

	Area ratio		Ki	Ki'	m
Exterior walls	m^2/m^2	0.719	0.55	0.396	
Windows	-	0.230	3.20	0.735	
Doors	-	0.051	2.50	0.128	
Roof	-	0.939	0.30	0.282	
"Outer"Floor 25%	-	0.235	0.29	0.070	
House Volume	m^3/m^3	2.582	0.29	0.748	
				α = 2.36	
Concrete Floor	-	0.113	2200		247.8
Concrete Partition Walls (ρ = 2.5·10E3)	-	0.020	2200		42.8
Light Partition Walls (ρ = 1.5·10E3)	-	0.08	1320		106.2
					m = 396.8

C for partition walls = 0.88 KJ/kg°C

β = (inner floor area/ gross ext. wall area) · Ki·(Ti-5)
= (0.235·3)·0.3·(20-5) = 3.17

$a = (Ko+Ki)/m = 1/m \cdot Kl/b$
$= (1/396.8) \cdot 24 \cdot 3600 \cdot 10E-3 \cdot Kl/b = 0.2177 \cdot Kl/b$ days

$b = Kl/(Ko=Kl)$ or $Ko+Kl = Kl/b$

$Kl = \alpha + \beta/(20-Tg)$ W/m3·°C

$Ko = Kl \cdot (20-Tg)/\theta$

where $\theta = \theta_o[(Ti-Tg)/(Ti-Tgo) \cdot (Kl/Klo)]^{3/4}$

$\theta_o = 36.4°C$ if $Tf = 80°C$ $Tb = 40°C$
$Tgo = -15°C$ $Ti = 20°C$
and $Klo = 2.451$ if $Tg = -15°C$

Hence $\theta = 1.292 \cdot (20-Tg)^{3/4} \cdot Kl^{3/4}$
and $Ko = 0.774 \cdot Kl \cdot (20-Tg)$

Appendix II: Boreholes and connection pipelines

All cost figures in this and subsequent sections are prices in July 1984.

The cost of boreholes is usually one of the larger items in the overall cost of a geothermal system. The cost depends strongly on the depth of the reservoir.

The following values were used in the analysis: The average depth of boreholes is 1200 m. The drilling cost for each borehole is 9·10E6 Kr (0.3 M$). Borehole material is 2.5·10E6 Kr (0.083 M$). Considering 8% annual rate of interest and 12 years life time, as well as 75% success of drilling the annual cost is US$ 69,300 for each borehole.

Fig. 16 shows typical connection pipelines in a geothermal field (Municipal Heating System of Reykjavik, Laugarnes). According to that the following values were taken:

Average length of a connection pipeline for each borehole is 2oo m. Average pipe diameter is 250 mm. Considering the pipe is polyurethane insulated and polyethylene covered, 8% rate of interest and 20 years life time, the annual cost of connection pipelines for each borehole is US$ 3,000.

Appendix III: Main transmission pipelines

The hot water transmission cost is estimated by using figures from reports by VGK Consultants (1982, 1983). The main transmission distances from the geothermal field to the energy market are taken as 18 km and, alternatively, 32 km. The temperature of the water is 85°C, the cooling of hot water in the house heating systems is 40°C and the annual equivalent peak load hours are taken as 4120. The pipes and pumping equipment are depreciated in 25 years with 8% annual rate of interest. The resulting cost curves are plotted in Fig. 17 a, b and c as follows:

(a) is the pumping cost per MW pumping capacity.

(b) is pipeline cost per km unit length of pipeline.

(c) is overall water transport cost per cubic meter supply water and per kWh supply water.

Curve (c) shows that the higher the flow rate, the lower the overall transport cost. For the 18 km long transmission pipeline the annual transport cost is 3.3 mills/kWh, if the total flow rate is 598 l/s; and 3.8 mills/kWh, if the total flow rate is 375 l/s. The average transport cost for each borehole is US$ 90,080 when the total flow rate is 598 l/s (17 boreholes), i.e. entirely geothermal energy; and the average cost for each borehole is US$ 111,400 when the flow rate is 375 l/s (11 boreholes), i.e. partly geothermal partly oil.

Although the transport cost for partly geothermal partly oil is higher than entirely geothermal per cubic meter supply water, or for each borehole, the annual energy cost is somewhat lower in the partly geothermal and partly oil case. But it is decided to use US$ 90,080 for each borehole in the above analysis, in order to simplify the problem.

Appendix IV: Distribution network

The types of the distribution networks are divided into two, i.e. single and double system.

The typical consumer connection systems in different cases in Iceland are shown in Fig. 18.

The distribution network cost in different heat density city regions in Iceland is shown in Table 6 and Fig. 19. These values were determined according to existing distribution networks of some conmunities in Reykjanes (Orkustofnun and Fjarhitun Consulting Engineers Ltd.).

Appendix V: Peak power plant

Through the new power plant (60 MW), which will be built for the Municipal Heating System of Reykjavik, the annual peak power plant cost is estimated at 70,200 Kr/MW, (15 years life time, 8% rate of interest) including maintainance and operating personnel. In this analysis the maximum peak load boiler capacity is 42 MW, the total annual cost is thus US$ 97,200.

The fuel oil price was taken as following:

Heavy oil cost is 7.72 Kr/l (8440Kr/ton, ρ = 915 Kg/m).

Oil-fired boiler efficiency is 80%. Heating value is 8.58 kWh/l.

In this analysis the oil fuel cost was taken as 0.9 Kr/kWh (30 US mills/kWh).

Appendix VI: Energy cost calculation result

All of the boreholes located in-city (ρ = 105 MW)

Power demand %	Energy demand %	Running hours	No. borehole	P R I C E ($)					Cumulative price($)	Energy cost $/kWh	
				Bore-hole	Electricity	Conn.-pipe	Transport	Sum		interv.	mean
23,4	40,0	8760	4	27,720	121,500	12,000		410,700	440,700	0,00189	0,00189
29,3	50,3	8600	5	69,300	29,800	3,000		102,100	512,800	0,00191	0,00190
35,2	60,4	8200	6	-	28,400	-		100,300	613,500	0,00197	0,00190
41,1	68,8	7400	7	-	35,700	-		98,000	711,500	0,00214	0,00192
47,0	75,3	6500	8	-	32,500	-		94,800	806,300	0,00235	0,00194
52,9	81,0	5400	9	-	18,700	-		91,000	897,300	0,00271	0,00197
58,8	86,6	4300	10	-	14,900	-		87,200	984,500	0,00327	0,00207
64,7	91,3	3100	11	-	10,700	-		83,000	1.067,500	0,00432	0,00214
Peak power use extra boreholes											
70,6	95,0	2100	12	69,300	7,280	3,000		79,580	1.147,080	0,00611	0,00229
76,5	97,9	1450	13	-	5,030	-		77,330	1.224,410	0,00861	0,00233
82,4	98,8	820	14	-	2,800	-		75,100	1.299,510	0,01478	0,00247
88,3	99,2	550	15	-	1,900	-		74,200	1.373,710	0.02177	0,00261
94,2	99,6	275	16	-	950	-		73,350	1.446,960	0.04299	0.00275
100,0	100,0	100	17	-	350	-		72,650	1.519,610	0.11730	0,00289
Oil fired peak power station 41.53 MW											
				station		fuel					
70,6	94,0	2100		16,243		437,305		453,548	1.521,048	0,03480	0,00304
76,5	97,9	1450		16,243		301,949		318,192	1.839,240	0,03540	0,00349
82,4	98,8	820		16,243		170,757		187,000	2.026,240	0,03680	0,00385
88,3	99,2	550		16,243		114,532		130,775	2.157,015	0,03840	0,00410
94,2	99,6	275		16,243		57,266		73,509	2.230,524	0,04310	0,00424
100,0	100,0	100		15,967		20,471		36,438	2.266,962	0,05880	0,00431

All of the boreholes located out-of-city (ρ=105 MW)

Power demand %	Energy demand %	Running hours	No. borehole	P R I C E ($)					Cumulative price($)	Energy cost $/kWh	
				Bore-hole	Electricity	Conn.-pipe	Transport	Sum		interv.	mean
23,4	40,0	8,760	4	27,720	121,500	12,000	360,320	771,020	771,020	0,00355	0,00355
29,3	50,3	8,600	5	69,300	29,800	3,000	90,080	192,180	963,220	0,00359	0,00356
35,2	60,4	8,200	6	-	28,400	-	-	190,780	1.153,980	0,00374	0,00358
41,1	68,8	7,400	7	-	25,700	-	-	188,080	1.342,060	0,00410	0,00362
47,0	75,3	6,500	8	-	22,500	-	-	184,880	1.526,940	0,00459	0,00366
52,9	81,0	5,400	9	-	18,700	-	-	181,080	1.708,020	0,00540	0,00376
58,8	86,6	4,300	10	-	14,900	-	-	177,280	1.885,330	0,00665	0,00396
64,7	91,3	3,100	11	-	10,700	-	-	173,080	2.058,380	0,00900	0,00412
Peak power using extra boreholes											
70,6	95,0	2,100	12	69,300	7,280	3,000	90,080	169,660	2.228,040	0,01303	0,00446
76,5	97,9	1,450	13	-	5,030	-	-	167,440	2.395,450	0,01863	0,00455
82,4	98,8	820	14	-	2,800	-	-	165,180	2.560,630	0,03251	0,00487
88,3	99,2	550	15	-	1,900	-	-	164,280	2.724,910	0,04820	0,00518
94,2	99,6	275	16	-	950	-	-	163,330	2.888,740	0,09590	0,00549
100,0	100,0	100	17	-	350	-	-	162,730	3.050,970	0,26270	0,00580
Oil-fired peak power station (41,53 MW)											
				station		fuel					
70,6	95,0	2100		16,243		437,305		453,548	2.511,928	0,03480	0,00502
76,5	97,9	1450		-		301,949		318,192	2.830,120	0,03540	0,00538
82,4	98,8	820		-		170,757		187,000	3.017,120	0,03680	0,00573
88,3	99,2	550		-		114,532		130,775	3.147,895	0,03840	0,00598
94,2	99,6	275		-		57,266		73,509	3.221,404	0,04310	0,00612
100,0	100,0	100		15,967		20,471		36,438	3.257,842	0,05880	0,00619

Appendix VII: Heat loss and effect of infiltration

1. Heat loss of district heating system

As indicated earlier in this report, the heating loss for district heating systems in Iceland are usually taken as 10% of the peak heat quantity (Karlsson, 1982). But this figure is just a mean value, because of the pipeline materials, the insulation, and the pipe arrangement etc. are quite variable. The most common heat losses in networks are normally between 15% and 25% of the annual heat consumption in Denmark (Larsen, 1978).

According to some figures which were obtained from 8 geothermal district heating transmission pipelines in Iceland (Bjornsson, 1980), heat loss is calculated and the results shown in Table 7. The heat losses for transmission pipelines in these existing system are 6% to 37%, but the majority are between 10% and 20%, based on annual energy consumption.

The heat loss for a distribution network is normally lower than in transmission pipelines of asbestos cement, usually between 5% to 10%, but higher than for well insulated transmission pipes.

2. Effect of infiltration

The heating load estimate is a computational procedure which accounts for the probable temperature occurring in a room or space to be heated at design temperature conditions.

The basic formula for the heat loss of the buildings is given by the equation:

$HL = A \cdot Kl \cdot (Ti-To)$ where HL = Heat Loss; A = Area of Exposed Surface, m^2; Kl= Coefficient of Transmisson, $KJ/hr/m^2/°C$; Ti = Indoor temperature, °C; To = Outdoor temperature, °C.

The magnitude of these losses depends on the design inside-outside temperature difference, construction materials, amount of insulation used, size of the building and the infiltration.

The infiltration is the cold air which leaks in through windows, doors and walls, because of wind pressure against the building and by difference in air density between the warm and cold air. The effect of wind on supply water temperature Tf (chill factor and infiltration) at the different design temperatures is plotted in Fig. 20.

These curves are based on figures from Hartwig (1983).