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GEOHERMAL HEATING

M. AUREILLE

E.D.F.
Direction des études et recherches
Division techniques des énergies nouvelles
Chatou

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Geothermal Heating

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"Analysis of the influence of the main variables and set of nomograms
enabling a rapid assessment to be made of the economic value and
performance of a geothermal heating installation".

Project leader:

Mr Aureille: Head of Division: New Sources of Energy

VII

Studies :

Mrs Lamethe-Parneix: Engineer in the Division:)
New Sources of Energy) responsibility
) for the
Mr Raymond: Technician in the Division:) general study
New Sources of Energy)

Mr Pourbaix: Engineer in the Division:
New Sources of Energy;
responsible for the study on heat distribution
networks.

EDF

Directorate for Studies and Research

6 quai Watier - 78400 - CHATOU

June 1980 :

PART ONE

INTRODUCTION

I - INTRODUCTION

The decision to build a geothermal heating plant generally requires the prior knowledge of a number of factors, some of which - such as the characteristics of the geothermal resources - cannot be determined at the time the decision is made. It is therefore very useful to estimate the degree to which a geothermal project can be influenced by the totality of these variables. This problem has necessitated the use of computer programs.

The aim of this study - following a brief reminder of the principle underlying the program (see paragraph II) - is to demonstrate the influence of the main variables (see paragraph III) and then to supply nomograms from which an initial estimate may be made - without having to use data-processing facilities (see paragraph IV) - of the viability of projects in both energy and economic terms.

The studies carried out by EDF and OET were divided up as follows : EDF concentrated on the effect of the variables on drilling (flow rate and temperature of the geothermal water) and on the network whereas OET concentrated on the effect of climate and the type of housing. As regards the central boiler plant, similar studies have been carried out showing two alternative schemes for the incorporation of heat pumps.

The graphs and nomograms contained in the report have been drawn up by EDF, using the same criteria to describe the housing accommodation and the plan for connecting the heating network to the geothermal resource.

In all cases, the likely influence on the project of all the variables is expressed in terms of energy and economic criteria.

PART TWO

DETAILS OF THE COMPUTER

PROGRAM

Note to reader:

Explanations of the various data abbreviations used in the report may be found in tables II.11 and II.12 on pages 15 & 16 respectively.

II- DETAILS CONCERNING THE COMPUTER PROGRAM

2.1. UNDERLYING PRINCIPLE

The GEOPAC-EDF-INFRATEL computer program processes data relating to the geothermal project and carries out the thermal and energy calculations relating to the various heating systems which use geothermal energy.

The calculation data are mainly variables whose effect on the viability of the project is described below.

The variables relate to the geothermal resource, climatic data, the premises to be heated, the options available in respect of the centrally-situated heating plant and economic data.

The various stages and operation of the computer program are diagrammatically represented in the simplified flow chart shown in figure II.1. The annual energy requirements are calculated on the basis of hourly data for the heating season bearing in mind the type and number of housing units and the climate. The calculations relating to thermal factors are then made in respect of the selected configurations for the respective positions of the geothermal exchangers, heat pumps, users and auxiliary boilers. The aggregate amounts of geothermal, electrical and auxiliary energy consumed by the housing units provide the basis for the energy balances for the geothermal heating project where there is either straight heat exchange or exchange via heat pumps and for comparing this system with conventional heating systems. The economic calculations then provide a basis for assessing the value of the project.

FIGURE II.1 : SIMPLIFIED FLOW CHART

2.2. THE BASIC DATA

2.2.1. Geothermal data

2.2.1.1. Water temperature

In order to cover most eventualities, three values have been used : i.e. 80°C, 60°C and 40°C.

The corresponding borehole depths are approximately 1800m, 1400m and 600 m.

2.2.1.2. Geothermal flow rate

To cover the range of possibilities, three values have been selected : 100, 200 and 300 m³/hr per extraction borehole.

No account has been taken of artesian phenomena.

2.2.1.3. Number of boreholes

It has been agreed to use the same number of injection boreholes as extraction boreholes.

2.2.1.4. Chemical constitution of the water

Except for the study on the effect of the chemical properties of the water, the water is assumed to be corrosive and to require the use of titanium exchangers.

2.2.2. Climatic data

The values used to obtain the results published in this report are the minimum and maximum daily outside air temperatures recorded at Orly during the heating period from 15 October 1976 to 20 May 1977.

This corresponds to a "continental"-type climate ; the effect of climate (oceanic, mediterranean etc.) has been investigated by OET and will be dealt with in a separate report which will also discuss the effect of the type of housing.

2.2.3. Operating data

2.2.3.1. Number of dwellings

In order to plot the curves, different numbers of dwellings have been considered : i.e. 2000, 2500, 3000, 4000, 4500 and 5000.

2.2.3.2. Average volume per standard housing unit

This was fixed at 186 m³.

2.2.3.3. Coefficient of median heat loss

This was fixed at 1.05 W/m³.°C.

2.2.3.4. Temperatures of the heating systems

Three types of heating unit were considered, i.e.

- radiators whose inlet-outlet temperatures are 90°C and 70°C respectively ;
- low temperature radiators, 70/50°C ;
- underfloor heating, 55/40°C.

As far as the EDF part of the report is concerned, the temperature settings up to 18°C- which are determined as a function of the external temperature - lie on straight lines (see figures II.2, II.3).

The detailed study of internal systems carried out by OET is not included in this report.

2.2.4. Technical data in respect of the equipment

2.2.4.1. Drilling pumps

The electrical power ratings used (extraction and injection pumps) are as follows :

- 150 kW at 100 m³/hr
- 200 kW at 200 m³/hr
- 325 kW at 300 m³/hr

FIGURE II.2 : SETTING CHARACTERISTICS OF THE 90/70°C RADIATORS AND THE 55/40°C UNDERFLOOR HEATING SYSTEM

FIGURE II.3 : SETTING CHARACTERISTICS OF LOW-TEMPERATURE RADIATORS (70/50°C).

2.2.4.2. Auxiliary pumps

The electrical power of the auxiliary pumps varies as a function of the flow-rate of the heat-carrying fluid in the system. It is defined by the following expression :

$$\text{AUX (in kW)} = 0.077 Q (\text{M}^3/\text{hr}) + 2.5$$

(see Figure II.4.)

2.2.4.3. Heat exchanger

This is composed of a number of heat-transfer units - fixed at 5 except in the paragraph describing the effect of this parameter.

2.2.4.4. Heat pump

The electrical power has been optimized in each of the cases investigated in such a way as to obtain the lowest possible discounted cost per useful thermie :

- i) the maximum permissible temperature at the condenser outlet was set at 85°C,
- ii) the average temperature difference between the water and the coolant (in the condenser and in the evaporator) has been estimated at 4°C,
- iii) the minimum permissible temperature difference between the condenser outlet and the evaporator outlet is 18°C,
- iv) the minimum temperature of the water at the evaporator outlet is 5°C,
- v) the minimum operating load on the heat pump is 10 % of the nominal value,
- vi) the ratio of the coefficient of practical performance to the coefficient of theoretical performance as a function of load has been defined on the basis of the following graph, drawn up from measurements taken at an existing plant (see Figure II.5).

FIGURE II.4 : GRAPH SHOWING THE POWER OF THE AUXILIARY PUMPS

FIGURE II.5 : VARIATION IN THE CURVE $a = f(\text{LOAD})$

2.2.5. Economic data valid for (June 1979)

2.2.5.1. Cost of conventional reference fuel

This has been fixed at FF 100 kth at the boiler outlet.

2.2.5.2. Cost of drilling

This cost varies with depth or with the temperature of the geothermal fluid. The cost pattern adopted is shown diagrammatically in Figure II.6. It has been based on information supplied by Gaz de France and the Bureau de Recherches Géologiques et Minières to which has been added a flat rate amount of FF 2.5 million to cover the cost of surface equipment and the network using the geothermal fluid.

FIGURE II.6. : COST OF A PAIR OF BOREHOLES AS A FUNCTION OF DEPTH

(1) Average estimate (drilling only) according to data supplied by the BRGM and GDF.

(2) Estimate (including surface equipment).

2.2.5.3. Cost of the heat exchanger

This cost is proportional to the heat transfer coefficient k and to the surface area S of the exchanger, i.e. :

Cost in FF = $700.000 \times KS$ where KS is expressed in Gcal/°C.

To this must be added the cost of additional equipment, i.e. : $500 (QP + QS)$ where QP and QS are the flow rates in the primary and secondary circuits of the exchanger expressed in m³/hr.

2.2.5.4. Cost of the heat pump

This cost has been calculated on the basis of the following curve (see Figure II.7) which has been obtained by interpolating data from several manufacturers. If the temperature at the condenser outlet (TC_{max}) is greater than 50°C, then the price of the pump is as follows : $(0.0125 TC_{max} + 0.375) P_1 \times P_N$, where P_N is the maximum heat capacity of the pump.

FIGURE II.7 : AVERAGE CURVE AND STANDARD DEVIATION OF THE COST, EXPRESSED IN FRANCS, PER THERMIE/HOUR DELIVERED BY THE HEAT PUMP

2.2.5.5. Cost of the fossil fuel boiler

This cost is proportional to the maximum power, P, which - when expressed in French Francs - is :
 cost of the boiler = 300 000 x P
 where P is in thermie/hour.

2.2.5.6. Cost of connection to the grid, of modification to the heating plants and of the requisite civil engineering work.

These costs have been excluded from the calculations in view of their likely fluctuations, and also because each case is specific and must be considered separately.

2.2.5.7. Cost of electricity

This has been calculated on the basis of the EDF's green tariff as valid for May 1979
 (see Table 11.8).

Tariff	Fixed annual premium Basic rate (francs per kW)	Energy prices (centimes per kWh)				
		Winter			Summer	
		Peak	Normal full demand	Off-peak	Normal full demand	Off-peak
Long period off-take	399.09	17.87	13.70	9.05	9.80	8.78
Auxiliary	232.03	26.22	18.43	9.61	12.67	9.24
General	148,50	37,36	21,12	9,70	14,07	9,33
Short period off-take	59.40	59.41	32.46	9.70	16.59	9.33
Emergency	66.82	59.41	32.46	9.70	16.59	9.33
Reactive energy (centimes per kVA/min) (invoicing rebate)		2.65 1.05			1.76 0.70	

TABLE II.8 : TARIFF FOR SURVEY OF CURRENT IN THE 5-TO 30-KV RANGE, EXCLUDING VAT (17,6%)

2.2.5.8. Fixed operating costs

Annual maintenance costs have been estimated as follows :

FF 285 000 for the geothermal system with a heat pump.

FF 240 000 for the geothermal system with simple heat exchange.

2.2.6. Energy data

The efficiency of the fossil fuel boiler has been set at 0.7. The equivalence in tonnes oil equivalent of the electrical power (expressed in kWh) is as follows :

1 toe = 4500 kWh.

2.2.7. General data

No use has been made of the possibility of switching off the heat pumps or the down-hole pumps at EDF peak periods.

On the other hand, it has been assumed that a single EDF contract covers the entire electrical plant, auxiliary drilling pumps and heat pumps.

2.3. THE CIRCUITS USED

2.3.1. Use of geothermal energy with simple heat transfer

The circuit where geothermal energy is used without a heat pump includes a geothermal heat exchanger, auxiliary boiler and the dwellings to be heated.

2.3.2. Use of geothermal energy with heat pump

Several types of circuit have been considered, i.e. those drawn up by the OET (not included in this report) and those of the EDF as illustrated in Figure II.9.

FIGURE II.9 : CIRCUIT FOR A GEOTHERMAL HEATING SYSTEM WITH HEAT PUMPS.

The circuit shown in Figure II.9 operates in different forms to meet the outside temperature conditions, i.e.

A. Where the outside temperature is sufficiently high for the geothermal energy to provide heat by single transfer, the heat pump is switched off. This eventuality is described in paragraph 2.3.I.

B. The heat pump is switched on, keeping the flow rates in the primary and secondary circuits in the geothermal heat exchanger at the same level. The evaporator cools part of the fluid returning from the heating unit whereas the condenser raises the heat level of the mixture consisting of the water leaving the exchanger and the return water.

C. A bypass cuts out the evaporator when the temperature difference between the condenser outlet and the evaporator outlet is too low ($18^{\circ}\text{C}.$).

D. The fossil fuel auxiliary boiler is put into operation to provide the requisite additional heating during the coldest period.

2.4. RESULTS OF THE PROGRAM

As can be seen from the simplified flow chart (see Figure II.1.), the initial calculations are designed to identify the annual requirements of the heating plant on the basis of data relating to climate and utilization. In the following graph (figure II.10) we have summarized these results, showing the relationship between the number of standard housing units and the annual consumption expressed in G Joules or G cal (10^9 Joules or 10^9 calories).

If the actual heating requirements of the urban area in question are known, it is possible to calculate the number of standard housing units ; this is the main parameter in all the nomograms constructed on the basis of the calculation results.

For a given project, e.g. using the data given in Table II.2. , the computer program can provide a number of interesting results on which a decision can be made as to whether or not to use geothermal heating. In particular, it shows the economic balance sheets (see Table II.12.), the energy balances (see Table II.13) and the curves showing the trend in the coefficient of efficiency of the heat pump, the temperature of the re-injected water and the curve of the load on the installation.

In order to compare the various options, we have selected four criteria on the basis of which we can examine the influence of the totality of the variables on the design of the installation : these criteria also served as the basis for plotting the nomograms.

FIGURE II.10 : ANNUAL HEATING REQUIREMENTS AS A FUNCTION OF THE NUMBER OF STANDARD HOUSING UNITS.

Energy criteria

The geothermal efficiency E is the proportion of geothermal energy in the total energy consumption of the housing units, i.e. the total residential heating requirements and the consumption of the auxiliary plant ; E is expressed as a percentage.

The criterion complementary to the geothermal efficiency E is the proportion of fossil-fuel energy in the total energy consumption of the housing units, also called "topping-up".

For each calculation, a comparison of primary energy consumption is made between geothermal heating and conventional heating. For each plant calculate the savings in tonnes oil equivalent obtained by the construction of a geothermal heating system (toe saved).

Economic criterion

The only economic criterion which can be used to compare various heating systems is the discounted cost per useful thermie. This cost is calculated on the basis of the investment required for the project and the operating cost. Since the official discount rate in France is 9 %, we have applied this rate over a period of 20 years.

GENERAL DATA

Temperature of the geothermal water	:	TEP	= 60°C
Flow rate in the geothermal well	:	QG	= 200.00 m ³ /h
Artesian flow rate	:	QGA	= 0.0 m ³ /h
Salinity	:	SAL	= 35.00 g/l
Rating of the extraction pumps	:	PEXT	= 60.00 kW
Rating of the injection pumps	:	PREINJ	= 140.00 kW
Number of geothermal borehole pairs	:	NFORAG	= 1
Number of EDF contracts	:	CONTRA	= 1
Flow rate in the heating network	:	QR	= 735.88 m ³ /h
Coefficient of efficiency	:	COP	= 5.29
Maximum temperature TCX	:	TCMAX	= 85.0°C

OPERATING DATA

First "user"

Type of heating unit	:	Underfloor heating (70.0/50.0°C)
Insulation coefficient	:	GLGT = 1.05 W/m ³ /°C
Volume of a standard housing unit	:	VLGT = 186.00 m ³
For an external temperature of	:	TEXT = -6°C
Inlet temperature of utilization	:	TEU = 69.8°C
Outlet temperature of utilization	:	TSU = 49.9°C
Heat flow of utilization	:	PU = 14658.7 th/h
Flow rate of utilization	:	QU = 735.9 m ³ /h
Number of housing units	:	NLGT = 3500

TABLE II, 11

GEOHERMAL HEATING SYSTEM INCORPORATING HEAT PUMPS

INVESTMENT

Price of drilling	PFO = 9.000.000.0 FF
Price of heat exchangers	PPEC = 699.997.0 FF
Additional equipment	PES = 467.949.9 FF
Price of the heat pump (PCOND = 3891.76 TH/H)	CAPAC = 1.215.367.0 FF
Price of the auxiliary boiler	CCAP = 2.906.249.0 FF
Distribution network	R = 0.0 FF
Investment	CI = 14.289.562.0 FF

OPERATING COST

Cost of electricity	CENERG = 643.993.9 FF
Cost of auxiliary energy	PFUEL = 433.705.7 FF
Maintenance cost	ENT = 285.000.0 FF
Operating cost	E = 1.362.699.0 FF

DISCOUNTING

Discount rate of 9 % applied to the balance-sheet total over a period of 20 years-balance-sheet	BIL = 27.276.080.0 FF
Proportion of the investment as a percentage in the balance-sheet total	CIP = 52,4 %
Proportion of the operating cost as a percentage in the balance-sheet total	EP = 47.7 %
<u>Cost per useful thermie</u>	<u>CTHU = 0.09632 FF</u>

GEOHERMAL HEATING WITHOUT HEAT PUMPS

Investment	CI = 13.813.967.0 FF
Cost of electricity	CENERG = 246.501.6 FF
Maintenance cost	ENT = 245.000.0 FF
Operating cost	E = 1.438.115.0 FF
Proportion of the investment as a percentage in the balance-sheet total	CIP = 50.2 %

Proportion of the operating cost as a
percentage in the balance-sheet total

EP = 49.9 %

Cost per useful thermie

CTHU = 0.09717 FF

CONVENTIONAL SYSTEM

Investment

CI = 4.397.608.0 FF

Operating cost

E = 3.028.109.0 FF

Proportion of the investment as a percentage
in the balance-sheet total

CIP = 13.3 %

Proportion of the operating cost as a
percentage in the balance-sheet total

EP = 86.8 %

Cost per useful thermie

CTHU = 0.11743 FF

TABLE II. 12

ENERGY CONSUMPTION

REQUIREMENTS: 124213.69 GJ (GJ = 10⁹ Joules)

EXPRESSED AS
PRIMARY ENERGY

GEOHERMAL HEATING WITH HEAT PUMPS

Electricity consumption	12162.87 GJ or	8.74%	1 toe = 4500 kWh	695.17 toe
Consumption of auxiliary energy	18128.89 GJ or	14.07%	25898.42 GJ ($\eta = 0.7$)	619.58 toe
Energy required for drilling	99526.62 GJ or	77.22%		

GEOHERMAL HEATING WITHOUT HEAT PUMPS

Electricity consumption	4669.14 GJ or	3.62%	1 toe = 4500 kWh	288.19 toe
Consumption of auxiliary energy	39568.48 GJ or	30.70%	56526.39 ($\eta = 0.7$)	1352.31 toe
Energy required for drilling	84683.69 GJ or	65.71%		

CONVENTIONAL HEATING SYSTEM (FUEL OIL, GAS OR COAL)

Electricity consumption	1062.90 GJ or	0.85%	1 toe = 4500 kWh	65.60 toe
Consumption of auxiliary energy	124213.69 GJ or	99.15%	177447.00 GJ ($\eta = 0.7$)	4245.14 toe

AMOUNT OF ENERGY SAVED BY USING A GEOHERMAL SYSTEM WITH
HEAT PUMPS :

2995.99 toe

AMOUNT OF ENERGY SAVED BY USING A GEOHERMAL SYSTEM
EMPLOYING SIMPLE HEAT TRANSFER :

2670.25 toe

TABLE II.13

PART THREE

INFLUENCE OF THE MAIN VARIABLES ON A GEOTHERMAL PROJECT

III. INFLUENCE OF THE MAIN VARIABLES ON A GEOTHERMAL PROJECT

In some cases, the specific nature of a geothermal operation may have an impact in the energy field, and hence on the economy; in others it may have a solely economic impact.

As regards the boreholes and the network, first of all, the flow rate, water temperature and pumping capacity will directly affect the energy balance of a geothermal heating project, whereas the chemical properties of the water and the addition of a distribution network will have an essentially economic impact.

As regards the centrally-situated heating plant, the choice of system and the capacity of the heat pumps will affect the energy balance, whereas the quality of the fossil energy will affect only the economics of the operation.

The size of an installation is determined chiefly by its users, although factors like climate, the number of standard housing units and the temperatures on entry to and return from the heating system will affect energy and economic results.

In addition, the costs of materials and discounting rates and periods will directly affect the economic viability of a project.

3.1. THE BOREHOLES AND THE NETWORK

3.1.1. Effect of flow rate and temperature of the geothermal water

These features of the geothermal resource are obviously of fundamental importance in any geothermal project.

However, it is possible for the positive nature of one of these factors to make up for a weakness of the other. In other words, geothermal efficiency with simple heat transfer is largely the same if a geothermal resource provides :

- (i) 100 m³/h of water at 80°C or 150 m³/h of water at 60°C for 3 000 housing units with 55/40°C underfloor heating (see Figure III.1);
- (ii) 120 m³/h of water at 80°C or 250 m³/h of water at 60°C for 3 000 housing units installed with internal systems which have inlet temperatures of 70°C and outlet temperatures of 50°C (see Figure III.2); or
- (iii) 160 m³/h of water at 80°C, if these 3 000 housing units are heated by 90/70°C radiators (see Figure III.3).

For the geothermal heating of 3 000 housing units with under-floor heating with simple heat transfer, geothermal efficiency is 50% with :

- (i) 300 m³/h of water at 40°C;
- (ii) less than 100 m³/h of water at 60°C;
- (iii) 60 m³/h of water at 80°C.

With other methods of heating (90/70°C or 70/50°C radiators), efficiency will not exceed 40% with water at 40°C whatever the geothermal flow.

Comparing the curves with or without heat pumps shows the energy benefits of such pumps, particularly at low geothermal temperatures. On curve III.2 for example, the heat pump doubles geothermal efficiency at 40°C and increases it by some 10% at 60°C and by a few per cent at 80°C, when flow rates are more than 200 m³/h.

Furthermore, although with simple heat transfer, increasing the geothermal flow always increases geothermal efficiency, with a

FIGURE III.1 : INFLUENCE OF GEOTHERMAL CONDITIONS (TEMPERATURE AND FLOW) ON GEOTHERMAL EFFICIENCY (55/40°C UNDER-FLOOR HEATING).

FIGURE III.2 : INFLUENCE OF GEOTHERMAL CONDITIONS (TEMPERATURE AND FLOW) ON GEOTHERMAL EFFICIENCY (70/50°C RADIATORS)

FIGURE III.3 : INFLUENCE OF GEOTHERMAL CONDITIONS (TEMPERATURE AND FLOW) ON GEOTHERMAL EFFICIENCY (90/70°C RADIATORS)

heat pump it has only a limited, or even negative, effect on geothermal efficiency when the geothermal temperature is low (40°C) and there is a high-temperature heating system ($90/70^{\circ}\text{C}$, $70/50^{\circ}\text{C}$).

From the energy point of view however, it should be stressed that, for geothermal water at low temperatures boosting the geothermal flow by pumping, if the porosity of the aquifer allows, is generally less beneficial than adding heat pumps.

In Figure III.1., for example, the extra energy contributed by the heat pump in the case of a borehole with a flow rate of $100\text{ m}^3/\text{h}$ at 40°C corresponds to an increase in flow of $150\text{ m}^3/\text{h}$, whereas with a flow rate of $100\text{ m}^3/\text{h}$ of water at 60°C , the increase in geothermal efficiency due to the heat pump is only equivalent to an extra flow of some $40\text{ m}^3/\text{h}$ of water.

The advantage of increasing the flow of geothermal water increases with the temperature of the water, as can be seen from Figure III.4. However, it also depends on the energy needs of the housing units, in other words the number of units and the temperature of their heating systems.

For example, if 3 500 housing units are heated by $70/50^{\circ}\text{C}$ radiators, increasing the flow from 200 to $300\text{ m}^3/\text{h}$ improves geothermal efficiency only very slightly, even if the geothermal water is at a temperature of 60°C .

FIGURE III.4 : INFLUENCE OF GOETHERMAL TEMPERATURE ON GEOTHERMAL EFFICIENCY FOR DIFFERENT GEOTHERMAL FLOW RATES.

Under these circumstances, the cost of a useful thermie of heat is the same for 100 m³/h at 80°C as it is for 200 m³/h at 49°C or 300 m³/h at 46°C (see Figure III.5). Whatever the geothermal flow, between 100 and 300 m³/h the cost of geothermal heat per thermie will exceed the cost of conventional heating per thermie, if the temperature is lower than 40°C.

FIGURE III.5 : INFLUENCE OF GEOTHERMAL TEMPERATURE ON THE DISCOUNTED COST PER USEFUL THERMIE FOR DIFFERENT GEOTHERMAL FLOW RATES

For information, Figure III.6 shows how geothermal temperatures and flow affect the quantity of tonnes oil equivalent (toe) saved. If 3 500 housing units with an annual consumption of the order of 30 000 kilothermies are fitted with 70/50°C radiators, it is possible to save 3 000 toe with 200 m³/h of water at 60°C or with 300 m³/h of water at some 53°C.

FIGURE III.6 : INFLUENCE OF GEOTHERMAL TEMPERATURE ON SAVINGS OF ENERGY (in toe) FOR DIFFERENT GEOTHERMAL FLOWS.

If the 3 500 housing units are heated by 90/70°C radiators and heat pumps are used, the benefit of increasing the geothermal flow depends more than ever on the temperature of the geothermal water.

If the geothermal water is at 40°C, efficiency is lower with a flow rate of 300 m³/h than with 200 m³/h, since the extra geothermal calories do not offset the extra energy consumed by the drilling pumps (see Figure III.7).

Similarly, increasing the geothermal flow within the 200 to 300 m³/h bracket only reduces the costs of a thermie if the temperature of the geothermal water is more than 47°C (see Figure III.8).

FIGURE III.7 : INFLUENCE OF GEOTHERMAL TEMPERATURE ON GEO-THERMAL EFFICIENCY FOR DIFFERENT GEOTHERMAL FLOWS.

FIGURE III.8 : INFLUENCE OF GEOTHERMAL TEMPERATURE ON DISCOUNTED COST PER USEFUL THERMIE FOR DIFFERENT GEOTHERMAL FLOWS.

3.1.2. Importance of pumping

Pumping can be extremely important if there is no artesian flow. In this study, we have had to make various assumptions about pumping capacity (see paragraph II.2).

In a project to heat 3 500 housing units (70/50°C) by means of geothermal water at a temperature of 60°C with simple heat transfer, pumping costs represent some 32% of operating costs if the flow rate is 300 m³/h, 17% if it is 200 m³/h and 9% if it is 100 m³/h.

In energy terms, over a year of geothermal heating with simple heat transfer, pumping and auxiliary installations consume in the order of :

- (i) 6920 GJ, or 427 toe, if flow rate QG = 300 m³/h;
- (ii) 4670 GJ, or 288 toe, if flow rate QG = 200 m³/h;
- (iii) 3770 GJ, or 233 toe, if flow rate QG = 100 m³/h;

for 3 500 housing units (70/50°C).

The higher the geothermal temperature (see Figure III.9) and the lower the number of housing units, the greater the incidence of pumping costs in the overall operating costs. If there are 2 000 housing units and the geothermal water is at 80°C and the QG of 200 m³/h, pumping costs reach 47% of running costs, since additional fuel costs account for a much smaller percentage.

3.1.3. Chemical constitution of geothermal water

The chemical properties of water, particularly its salinity, have a slight influence on heat exchange between geothermal water and the water in the heating network. However, considering the probable salinity values of geothermal water (between 0 and 150 grams per litre), this factor has only a very slight effect

FIGURE III.9 : PUMPING COSTS AS PROPORTION OF OPERATING COSTS AT VARIOUS GEOTHERMAL TEMPERATURES.

on energy balances. Apart from salinity however, it is often the aggressivity of the water which adds to the cost.

It is possible in fact to have mild, non-aggressive water like that used at Mont-de-Marsan in the South of France, or aggressive geothermal water like that of Creil or Melun in the Paris Basin. If the water is of the first type, the exchanger can be made of stainless steel instead of titanium and the geothermal water can be discharged into streams if it is properly cooled; this yields a substantial investment saving, since a large proportion of the cost of the reinjection borehole is included in the economic balance (see paragraph 3.4).

3.1.4. Reinjection temperature

Reinjection temperature very much depends on geothermal heating conditions. If it drops, this is a sign that the heat in the geothermal water is being used more fully as a result of improvements to the installation.

The main factors which affect the reinjection temperature are the temperature at which the water returns from the heating system and the geothermal temperature, as shown in Figure III.10 and III.11.

These curves show how reinjection temperatures change during the heating season, for various geothermal temperatures in the case of 3 500 housing units fitted with 70/50°C radiators. The geothermal flow is 100 m³/h.

If a heat pump is used in the conventional system for extracting geothermal heat using an exchanger, this substantially reduces the reinjection temperature, as can be seen by comparing Figures III.10 and III.11.

Figure III.10 shows the results obtained from geothermal heating with heat pumps while Figure III.11 shows the reinjection temperatures if simple heat transfer is used.

FIGURE III.10 : CHANGES IN THE REINJECTION TEMPERATURE DURING ONE HEATING SEASON AND AS A FUNCTION OF SEVERAL DIFFERENT GEOTHERMAL WATER TEMPERATURES (80°C, 60°C and 40°C). GEOTHERMAL ENERGY WITH HEAT PUMPS.

FIGURE III.11 : CHANGES IN THE REINJECTION TEMPERATURE DURING ONE HEATING SEASON AND AS A FUNCTION OF SEVERAL DIFFERENT GEOTHERMAL WATER TEMPERATURES (80°C, 60°C AND 40°C). GEOTHERMAL ENERGY WITH SIMPLE HEAT TRANSFER.

3.1.5. Networks

There can be two kinds of network in a geothermal heating installation :

- (i) the geothermal water network, which is called the transfer network and which carries the water from the boreholes to the centrally-situated heating plant and back to the reinjection borehole;
- (ii) the network of distributing water for heating to housing units.

The transfer network may be very short if the boreholes are sunk near the housing area, as is the case with the Villeneuve-La-Garenne project in France, or it may extend several kilometres if a number of boreholes are required and cannot be sunk near the centrally-situated heating plant, as is the case at Creil (where the network is 7,300 kilometres).

In the case of Creil, where temperature losses are very slight, we could assume that the temperature of the geothermal water leaving the borehole was the same as the temperature of the water entering the geothermal exchanger.

This transfer network was taken into account to add on a lump-sum cost to the cost of sinking the boreholes (see paragraph 2.5.2).

The study of the distribution network is very important and particularly complicated if detailed plans for the network are not available. In this report, we have made the calculation for the geothermal heating installation independently of the heating network; we have therefore been considering an installation diverced from the network. A special study has been made of distribution networks and a computer calculation programme worked out. The results are given in the form of graphs in Annex 1.

3.2. THE CENTRALLY-SITUATED HEATING PLANT

3.2.1. Influence of the configuration

Generally, the centrally-situated heating plant includes the geothermal heat exchangers, the heat pumps and the auxiliary boilers required. The design of these various heating installations has to be specially worked out for each individual case. However, for the purposes of this contract we have elected to study two configurations, one which has been taken over by the OET and is not included in this report and the other which is shown in Figure II.10 ; it has enabled us to study the influence of different variables and to plot the nomograms which we have included.

Generally, it is only possible to arrive at the optimum configuration if there is full information about the temperature and flow of the geothermal resource and the conditions of use (number of housing units, type of installations, climate, hours of sunshine, etc.).

3.2.2. Size of the equipment - influence of the exchanger

An exchanger can be described according to its number of transfer units (NTU) defined as :

$$NTU = \frac{KS}{Min}$$

Min is the minimum value of the expression (mf x mh) calculated for the primary and secondary circuits of the geothermal heat exchanger, where mf is the mass flow and mh the mass heat, K the overall heat transfer coefficient and S the area of the total exchange surface.

This value can also be expressed as the ratio between the temperature difference divided by the hot fluid and the average

logarithmic difference. It is directly connected with efficiency, defined as the ratio between the quantity of heat actually exchanged and the quantity of heat which can be exchanged.

The greater the NTU, the better the recovery of heat energy, although the cost of the exchanger increases with NTU.

The optimum economic solution should be the objective when selecting the exchanger. Figure III.12 shows the influence NTU can have on the cost per useful thermie and the tonnes of oil equivalent saved. It should be remembered that the cost per thermie has a different minimum level depending on whether or not heat pumps are used.

For studying a specific case, it would be worth optimizing the dimensions of the heat exchanger and the heat pumps. However, in this general study, we chose an NTU which corresponds very closely with the optimum in most cases and all the other variables were studied with an exchange such that $NTU = 5$.

3.2.3. Heat pumps

3.2.3.1. Study of the optimization of the heat pumps

Heat pumps are refrigerating machines connected to two sources, furnishing heat to the hot source and taking heat from the cold source. These two functions of the machine are well suited to the heating of housing units by means of geothermal hot water because they make it possible :

- (i) to cool down the cold source substantially , thus extracting more calories from the geothermal water;
- (ii) to heat up the hot source - in this case, the water leaving the geothermal exchanger - to the level required for use.

FIGURE III.12 : INFLUENCE OF THE CHOICE OF EXCHANGER (NTU)

Extremely hot water (approximately 90°C) can be obtained at the condenser outlet and premises requiring these temperatures can be heated entirely by geothermal energy combined with heat pumps. However, these high temperatures are only required for a few days in each year and the extra investment in higher capacity heat pumps would only be paid off during these few days.

The most advantageous economic solution therefore has to be sought when deciding on heat pump capacity. By way of example, we plotted changes in the cost per useful thermie for 5 000 housing units heated by 90/70°C radiators as a function of the rated capacity of the heat pump (see Figures III.13 and III.14). All these curves show a minimum which varies according to the flow (see Figure III.13) and the temperature of the geothermal water (see Figure III.14).

FIGURE III.13 : STUDY OF THE SIZE OF THE HEAT PUMP.
INFLUENCE OF THE GEOTHERMAL FLOW RATE.

FIGURE III.14 : STUDY OF THE SIZE OF THE HEAT PUMP.
EFFECT OF THE TEMPERATURE OF THE GEOTHERMAL WATER.

Of course, the specific characteristics of the users, e.g. the types of interior systems (see Figure III.15) and the number of housing units, also affect the size of the heat pumps (see Figure III.16). It is even true to say that the size of the heat pump depends far more on conditions of use than on geothermal conditions. In fact, although the geothermal flow does have a slight effect on the economics of the heat pump size (see Figure III.13), the temperature of the geothermal water has only a very slight bearing on the choice of the electrical noting of heat pumps. However, the example chosen is for high-temperature radiators, the effect of the temperature of the geothermal water being more important if housing units are fitted with low-temperature systems.

The factor governing the size of the heat pump is the number of housing units or the annual heat consumption of all the "consumers". In Figure III.16 we showed how the capacity of the heat pump affects cost per thermie for various numbers of housing units.

The percentages are the proportion of the maximum heat taken off by the "consumer" accounted for by the heat at the heat pump condenser.

It can be seen that if the number of housing units exceeds 2 500, the capacity of a heat pump need only represents some 20% of capacity for each temperature drop of 7°C outside for the discounted cost per thermie to be less than with simple heat transfer. On the other hand, if the number of housing units is low (less than 2 300), simple heat transfer is more economic than the use of a heat pump, even if it represents only 40% of capacity.

FIGURE III.15 : STUDY OF HEAT PUMP SIZE.
INFLUENCE OF THE TEMPERATURE OF THE HEATING SYSTEM.

FIGURE III.16 : INFLUENCE OF THE NUMBER OF HOUSING UNITS ON THE SIZE OF THE HEAT PUMPS

These curves were plotted for housing units fitted with radiators whose inlet water temperature is 90°C when the outside temperature is -7°C and whose outlet temperature is 70°C . If the same number of housing units had heating units designed for a lower temperature eg. $70/50^{\circ}\text{C}$ or $55/40^{\circ}\text{C}$ this would not alter the size of the heat pump very much (see Figure III.15).

3.2.3.2. - Influence of the heat pump

The influence of the heat pump in the energy balance of a geothermal heating project was discussed in paragraph III.1.

A heat pump always increases geothermal efficiency; the greater the pump's capacity the greater the increase. The same applies to savings in primary energy (see Figure III.17). However the advantage of fitting a geothermal heating installation with heat pumps is usually evaluated on the basis of economic criteria like the cost per useful thermie, rather than energy criteria like geothermal efficiency or the amount of primary energy saved.

FIGURE III.17 : INFLUENCE OF THE HEAT PUMP ON SAVINGS OF PRIMARY ENERGY AS A FUNCTION OF GEOTHERMAL TEMPERATURE

Thus, considering the investment cost of the heat pump and its electricity consumption, the use of heat pumps is only justified in certain circumstances. For example, if the geothermal flow is $200 \text{ m}^3/\text{h}$ there is no economic advantage in using a heat pump if the water is at a temperature of 80°C ; if the water is at 60°C it may be justified if there are sufficient housing units and if the water is at 40°C (see Figure III.18) it is always economic with low temperature radiators ($70/50^\circ\text{C}$).

When the temperature in the heating system drops, the use of heat pumps is not so beneficial as geothermal water does not always need to be re-heated (see Figure III.19).

On the other hand, heat pumps are of substantial economic benefit in old buildings fitted with conventional radiators at $90/70^\circ\text{C}$ (see Figure III.20).

3.3. INFLUENCE OF CONDITIONS OF USE

The conditions imposed by users or consumers of heat are as important as the nature of the geothermal resource. The choice of which housing complexes have to be heated is determined by:

- (i) the climatic region, the number of housing units and the type of units, and thus the annual energy requirements;
- (ii) the heating system setting curves.

Actual requirements are calculated from the first two parameters. Paragraph II.2 explained the specifications adopted for the purposes of this study. The influence of these parameters is covered by OET in another report.

FIGURE III.18 : INFLUENCE OF THE HEAT PUMP ON THE COST PER USEFUL THERMIE (90/70°C RADIATORS)

FIGURE III.19 : INFLUENCE OF THE HEAT PUMP ON THE DISCOUNTED COST PER THERMIE (55/40°C "USERS")

FIGURE III.20

3.3.1. Climatic data and free heat

The meteorological data used was obtained from Orly for the year 1976-1977.

The amount of sun and free heat differs according to the type of housing or flats their exposure, etc.

We allowed for free heat when calculating the heating requirements for housing units as follows: between 7am and 6pm, the outside temperature was increased by $\Delta T^{\circ}\text{C}$ and between 10am and 4pm by ΔTX . Thus, the free heat is greater in the middle of the day when there is more sunshine and housing units are more likely to be occupied. Heating requirements for the same number of housing units vary according to the temperature differences ΔT and ΔTX selected. The correspondence between heating requirements and the number of housing units is shown in Figure III.21 for different temperature differences resulting from the supply of free heat.

FIGURE III.21

Sunshine may satisfy a substantial proportion of requirements. With the values taken for the study as a whole, it covered nearly 12.5 % of requirements (see Figure III.22). To give some indication, Figure III.23 shows the number of housing units this represents.

FIGURE III.22

FIGURE III.23

3.3.2. Influence of type of housing on heating requirements

The heating requirements are equivalent to the heat losses from the dwellings and are therefore proportional to the volume V of the dwellings, their insulation coefficient of G and the difference between the outside temperature and the ambient temperature indoors. New buildings are generally better insulated ($G < 1 \text{ W/m}^3\text{ }^{\circ}\text{C}$) than old buildings ($G \approx 1.5 \text{ W/m}^3\text{ }^{\circ}\text{C}$). Depending on the type of housing to be heated by geothermal energy, requirements for 3 500 housing units may vary from 95 000 G joules to 177 000 G joules, a variation of some 46% (see Figure III.24).

FIGURE III.24 : INFLUENCE OF THE INSULATION COEFFICIENT OF BUILDINGS ON HEATING REQUIREMENTS

In all cases for which nomograms have been plotted, an average insulation coefficient of $G = 1.05 \text{ W/m}^3 \text{ } ^\circ\text{C}$ was assumed. Figure III.25 shows the effect of this on the cost per thermie.

In buildings are not very well insulated, annual heating requirements are higher, a fact which makes geothermal energy more economic.

FIGURE III.25 : INFLUENCE OF THE INSULATION COEFFICIENT OF BUILDINGS ON COST PER USEFUL THERMIE.

3.3.3. Influence of the temperature of heating systems

The heat level of indoor systems is extremely important in any geothermal heating project. If it is low, it may be sufficient to use geothermal energy with simple heat transfer; otherwise heat pumps and a supplementary energy source have to be added.

The lower the geothermal temperature, the more it affects geothermal efficiency and the cost per thermie.

For example, geothermal efficiency for 3 500 housing units and with water at 40°C is 67.5% for housing units fitted with under-floor heating and 32% for units fitted with 90/70°C radiators.

If the geothermal water has a temperature of 80°C, the operating temperature of the heating units is less important : efficiency is 92% with 55/40°C underfloor heating and 84% with 90/70°C radiators (see Figure III.26).

Temperature has an appreciable effect on savings of primary energy, irrespective of the temperature of the geothermal water (see Figure III.27).

FIGURE III.26 : INFLUENCE OF GEOTHERMAL TEMPERATURE ON GEOTHERMAL EFFICIENCY FOR VARIOUS TEMPERATURES OF HEATING SYSTEM.

It is important to know the straight lines which show the settings of the heating units when deciding on a geothermal heating project since, even with the same temperature and flow conditions (60°C and $200\text{ m}^3/\text{h}$, for example), the cost per thermie for 3 500 housing units varies by more than 20% depending on whether they are fitted with radiators or underfloor heating (see Figure III.28). Incidentally, these results were obtained for a system fitted with a heat pump, which reduces the importance of the setting temperatures.

In fact, installing $90/70^{\circ}$ radiators instead of $55/40^{\circ}\text{C}$ underfloor heating reduces geothermal efficiency by some 27% geothermal energy if simple heat transfer is used and some 17% if heat pumps are added (see Figure III.29). A heat pump improves geothermal efficiency, chiefly because - by cooling the water which leaves the heating system - it makes it possible to

FIGURE III.27: INFLUENCE OF GEOTHERMAL TEMPERATURE ON TONNES OF OIL EQUIVALENT SAVED FOR VARIOUS HEATING SYSTEM TEMPERATURES.

FIGURE III.28 : INFLUENCE OF GEOTHERMAL TEMPERATURE ON THE DISCOUNTED COST PER THERMIE FOR VARIOUS HEATING SYSTEM TEMPERATURES.

achieve fuller use of the geothermal resource. We used the results obtained for the three types of heating system studied to plot changes in geothermal efficiency according to the temperature at which the water leaves the heating system, with and without heat pumps (see Figure III.30). The heat pump increases geothermal efficiency even more in cases where water leaves the heating units at high temperatures (it is 48% instead of 28% for a TS temperature of 70°C and 62% instead of 46% for a TS temperature of 40°C).

However, in spite of the heat pump, the geothermal efficiency of heating housing units with 90/70°C radiators is lower than if these units had 55/40°C underfloor heating.

3.4. ECONOMIC VARIABLES

3.4.1. Influence of the cost of materials

Investment accounts for a large proportion of the cost of a geothermal heating project; some 50% in heating 3 500 housing units with water at 60°C (see Figure III.31).

The main investment is the cost of sinking the boreholes. We have plotted how the cost of the boreholes affects the discount cost per useful thermie (Figure III.32) for a geothermal installation with heat pump. Under the same conditions (3 500 units fitted with 70/50°C radiators), the cost of the heat pump has only a slight effect on the discounted cost per thermie. Even if the price of the heat pump were twice that used for the calculations, the cost per thermie would only increase from 8.3 to 8.65 centimes for geothermal water at 80°C or from 9.90 to 10.2 centimes for water at 60°C (see Figure III.33).

FIGURE III.29 : INFLUENCE OF THE INDOOR SYSTEMS ON GEOTHERMAL EFFICIENCY

FIGURE III.30 : INFLUENCE OF THE OUTLET TEMPERATURE FROM THE HEATING SYSTEM ON THE PROPORTION OF GEOTHERMAL ENERGY USED TO SUPPLY HEAT.

FIGURE III.31 : PROPORTION OF INVESTMENT IN TOTAL COST

FIGURE III.32 : INFLUENCE OF THE COST OF THE BOREHOLE ON THE DISCOUNTED COST PER USEFUL THERMIE.

FIGURE III.33 : INFLUENCE OF THE COST OF THE HEAT PUMP ON THE COST PER THERMIE

3.4.2. Influence of energy costs

Although investment accounts for a very large proportion of the cost of a geothermal heating project (see Figure III.31), the costs of electricity and additional energy supplies also substantially affect the discounted price per thermie.

In the example given in Figure III.34, namely 3 500 housing units fitted with 70/50°C radiators and heated with 200 m³/h of geothermal water at a temperature of 60°C, the cost per

useful thermie with a heat pump is less than for geothermal heating with simple heat transfer, as long as the average cost of a kWh of electricity is less than 23 centimes. In both cases, it is still lower than the cost of conventional heating (per thermie) even if the cost of a kWh of electricity reaches 40 centimes, since the cost of the extra fossil-fuel energy is fixed at 10 centimes per thermie.

FIGURE III.34 : INFLUENCE OF THE COST OF ELECTRICITY ON THE DISCOUNTED COST PER THERMIE.

The cost of fossil-fuel energy to supplement geothermal energy is more critical when geothermal energy is used with simple heat transfer (see Figure III.35).

FIGURE III.35 : INFLUENCE OF THE COST OF ADDITIONAL ENERGY ON COST PER USEFUL THERMIE.

3.4.3. Influence of the discount rate and period

Arbitrary assumptions were made for these two economic variables: 9% for the discount rate and 20 years for the discounting period.

If the discounting period were less than this, few geothermal heating projects would be more economic than conventional heating, which requires much less investment. The curve in Figure III.36 shows how the cost per useful thermie varies according to the discounting period.

FIGURE III.36 : CHANGES IN THE COST PER THERMIE DISCOUNTED AT 9% ACCORDING TO THE DISCOUNTING PERIOD.

IV -- SET OF NOMOGRAMS

THIS PART OF THE REPORT CONTAINS A SET OF NOMOGRAMS PLOTTED FROM DATA OBTAINED FROM OUR COMPUTER PROGRAM THEY PROVIDE A RAPID INDICATION OF THE COST-EFFECTIVENESS OF A PARTICULAR GEOTHERMAL HEATING PROJECT.

THE REQUISITE DATA ARE AS FOLLOWS :

- GEOTHERMAL CHARACTERISTICS : TEMPERATURE (THE FLOW RATE, WITH PUMPING, IS RECKONED TO BE EQUIVALENT TO $200 \text{ m}^3/\text{hr}$);
- UTILIZATION CHARACTERISTICS: NUMBER OF HOUSING UNITS OR ANNUAL GEOTHERMAL ENERGY CONSUMPTION FOR HEATING AND TEMPERATURE OF THE HEATING ELEMENTS.

THE NOMOGRAMS PROVIDE INFORMATION ON :

- THE PROPORTION OF SUPPLEMENTARY FOSSIL ENERGY;
- THE DISCOUNTED COST PER USEFUL THERMIE;
- THE SAVING IN PRIMARY ENERGY EXPRESSED AS TONNES OIL EQUIVALENT.

FOR A GEOTHERMAL HEATING PROJECT, WHITH HEAT PUMPS OR NO, THE FIGURES ARE TO BE INTERPRETED AS FOLLOWS :

- (I) FIGURES IV.1 TO IV.6 ARE VALID IF THE HEATING ELEMENTS ARE $90/70^\circ\text{C}$ RADIATORS;
- (II) FIGURES IV.7 TO IV.12 ARE VALID FOR DWELLINGS FITTED WITH $55/40^\circ\text{C}$ UNDERFLOOR HEATING SYSTEM;
- (III) FIGURES IV.13 TO IV.18 ARE VALID FOR DWELLINGS HEATED BY $70/50^\circ\text{C}$ RADIATORS.

4.1. NOMOGRAMS PLOTTED FOR DWELLINGS FITTED WITH 90/70°C RADIATORS

4.1.1. Geothermal heating with heat pump

Determination of the following values as a function of the number of standard housing units and temperature of the geothermal energy :

- proportion of supplementary fossil energy in the annual amount of heat supplied to dwelling (cf. Figure IV.1);
- cost per useful thermie discounted at 9% over 20 years (cf. Figure IV.2);
- savings in primary energy from geothermal heating compared with conventional oil-fired heating systems (cf. Figure IV.3).

4.1.2. Geothermal heating with simple heat transfer

Determination of the following values as a function of the number of standard housing units and the temperature of the geothermal fluid:

- proportion of supplementary fossil energy in the annual amount of heat supplied to dwellings (cf. Figure IV.9);
- cost per useful thermie discounted at 9% over 20 years (cf. Figure IV.5);
- savings in primary energy from geothermal heating compared with conventional oil-fired heating systems (cf. Figure IV.6).

FIGURE IV.1

FIGURE IV.2

FIGURE IV.3

FIGURE IV.5

FIGURE IV.6

4.2. NOMOGRAMS PLOTTED FOR DWELLINGS HEATED BY 55/40°C UNDERFLOOR HEATING SYSTEMS

4.2.1. Geothermal heating with heat pump

Determination of the following values as a function of the number of standard housing units and temperature of the geothermal energy :

- proportion of supplementary fossil energy in the annual amount of heat supplied to dwellings (cf. Figure IV.7);
- cost per useful thermie discounted at 9% over 20 years (cf. Figure IV.8);
- savings in primary energy from geothermal heating compared with conventional oil-fired heating systems (cf. Figure IV.9).

4.2.2. Geothermal heating with simple heat transfer

Determination of the following values as a function of the number of standard housing units and the temperature of the geothermal fluid :

- proportion of supplementary fossil energy in the annual amount of heat supplied to dwellings (cf. Figure IV.10);
- cost per useful thermie discounted at 9% over 20 years (cf. Figure IV.11);
- savings in primary energy from geothermal heating compared with conventional oil-fired heating systems (cf. Figure IV.12).

Discounted cost in French francs par usefuel thermie

FIGURE IV.9

Underfloor heating 55/40°C
 Geothermal flow rate: 200 m³/h
 Geothermal heating with simple
 heat transfer

FIGURE IV.10

N = Number of standard housing units
 T = Temperature of geothermal fluid

FIGURE IV.11

FIGURE IV.12

4.3. NOMOGRAMS PLOTTED FOR DWELLINGS HEATED BY 70/50°C RADIATORS

4.3.1. Geothermal heating with heat pump

Determination of the following values as a function of the number of standard housing units and temperature of the geothermal energy :

- proportion of supplementary fossil energy in the annual amount of heat supplied to dwellings (cf. Figure IV.13);
- cost per useful thermie discounted at 9% over 20 years (cf. Figure IV.14);
- savings in primary energy from geothermal heating compared with conventional oil-fired heating systems (cf. Figure IV.15).

4.3.2. Geothermal heating with simple heat transfer

Determination of the following values as a function of the number of standard housing units and the temperature of the geothermal fluid :

- proportion of supplementary fossil energy in the annual amount of heat supplied to dwellings (cf. Figure IV.16);
- cost per useful thermie discounted at 9% over 20 years (cf. Figure IV.17);
- savings in primary energy from geothermal heating compared with conventional oil-fired heating systems (cf. Figure IV.18).

FIGURE IV.13

FIGURE IV.15

FIGURE IV.16

% additional heat

Radiators: 70/50°C
 Geothermal flow rate: 200 m³/h
 Geothermal heating with
 simple heat transfer

N = Number of standard housing units
 T = Temperature of geothermal fluid

FIGURE IV.17

FIGURE IV.18

PART FIVE

EXAMPLES OF HOW NOMOGRAMS CAN BE USED

CONCLUSIONS

V. EXAMPLES OF HOW NOMOGRAMS CAN BE USED AND CONCLUSIONS

Let us take a geothermal heating project for dwellings whose total consumption is known, e.g. 37 650 MWh or 32 379 kth/h.

The number of standard housing units (3 650) and the characteristics of the geothermal resource such as :

- (1) temperature -58°C
- (2) pumped flow rate - 200 m³/h.

can be determined from curve II.11.

We can now work out the discounted cost per useful thermie, the proportion of supplementary energy and the saving in primary energy for a system using a heat pump or a system with simple heat transfer. Taking the example of a system using a heat pump :

- (1) If the radiator temperature range is 90/70°C

$$N/T \neq 63 \quad \text{where } N = 3\,650$$

$$T = 58$$

By interpolating the curves in Figure IV.2, the discounted cost per thermie can be calculated 11.6 centimes and by interpolating the curves in Figure IV.3 the saving in primary energy can be determined 2 300 toe .

- (2) If the heating elements are 55/40°C underfloor heating system, the discounted cost per useful thermie is 9 centimes and the saving in primary energy 3 300 toe .

The results for a geothermal heating system with simple heat transfer can be calculated in the same way.

Since geothermal conditions are often uncertain, it may be worthwhile calculating the range of variation in the cost per

thermie and in the saving in primary energy as a function of the geothermal temperature :

If $T = 58^{\circ}\text{C} \pm 4^{\circ}\text{C}$

$\frac{1}{T} = 62^{\circ}\text{C}$ $N/T = 59$

90/70°C radiators

$C = 11.15$ centimes

toe = 2 500 toe

55/40°C underfloor heating

$C = 8.6$ centimes

toe = 3 450 toe

$\frac{2}{T} = 54^{\circ}\text{C}$ $N/T = 67.6$

90/70°C radiators

$C = 12.1$ centimes

toe = 2 080 toe

55/40°C underfloor heating

$C = 9.25$ centimes

toe = 3 130 toe

If the price per thermie of fossil energy varies by 10 centimes (basis of calculation), the discounted cost per useful thermie of heating can be calculated from the curves showing the proportion of fossil energy in the energy consumption of the dwellings as a function of the number of dwellings and temperature of the geothermal water.

Thus, the preceding example of a geothermal heating system with a heat pump for 3 650 dwellings with 90/70° radiators where $T = 58^{\circ}\text{C}$ and $N/T = 63$, the proportion of additional heat is 29%

for an annual consumption of 32 379 kth, i.e. 9 390 kth of fossil fuel.

The annual fuel costs at 12 centimes/th would be FF 1 126 800 instead of FF 939 000 and the discounted cost per thermie of geothermal heating would be 12.2 centimes instead of 11.6 centimes.

Finally, it can be concluded that the main variables which influence a project for the geothermal heating of existing dwellings are :

- (1) the actual consumption of housing units which are in turn determined by their geographical location (climate), characteristics (size, insulation, aspect) and number;
- (2) internal heating systems which determine the temperature of the return water to the boiler plant;
- (3) the characteristics of the geothermal resource (chiefly temperature, flow rate and constitution of water);
- (4) the type of supplementary energy used which determines the cost of the additional energy.

Each individual case can be dealt with by adapting this method to the constraints of the site and the utilization characteristics.

The cost of the hot water distribution network can be taken into account by the method set out in Annex I. However, there is no particular need to have a group of several boreholes for geothermal energy which occurs naturally at the site of the dwellings itself.

The set of nomograms given here provide a rapid indication of :

- (1) the proportion of supplementary fossil energy;
- (2) the discounted cost per useful thermie;

(3) the saving in primary energy by using the main variables.

For a proposal project whose conditions differ from the hypotheses used to plot the nomograms a range of determined values can be worked out from the curves showing the influence of the various variables on the results.

COMMISSION OF THE EUROPEAN COMMUNITIES

ANNEX I

PROGRAM FOR HEAT DISTRIBUTION NETWORKS

Contract No 584.78-7 EGF

ANNEX I

PROGRAM FOR HEAT DISTRIBUTION NETWORKS1. PURPOSE

The aim of the MERCURE computer program (model investigating the use and recovery of heat in heating networks) is to determine the dimensions and to evaluate the cost of a heat distribution network for which a nomogram has been plotted and main data (heat demand at each point, selected temperature levels, etc.) are known.

The main program outputs are :

(I) of a technical nature :

- (i) diameter of pipes;
- (ii) head losses and pump ratings;
- (iii) heat losses.

(II) of an economic nature :

- (i) cost of larging pipes, and installing pumping stations and connections;
- (ii) annual maintenance and electricity costs for pumping.

Pipe sizes - and hence the total pressure head of the pumps - can be determined to minimize total discounted costs (investment plus operating costs). Account can be taken of a phased programme of network construction and customer connection.

Before such calculations can be carried out we must of course know the average unit costs or "probable" costs such as :

- (1) cost per linear metre of urban network as a function of diameter;

- (2) specific cost (FF/kW) of pumping stations;
- (3) cost of a connection as a function of the type of sub-station (exchange or mixing) and its rating.

2. UNIT COST OF PIPING AND SUB-STATIONS

2.1. Piping

After studying a number of different costs for urban heating network projects we can estimate the average costs as a function of diameter for :

- (1) civil engineering work (excavation, concrete conduits, etc.);
- (2) thermal equipment (piping, valves, relief valves, etc);
- (3) the total cost per linear metre of network (see Figure 1) which includes the above two items of expenditure and additional costs arising from particular problems encountered (obstacle necessitating detours, extreme depths, wet subsoil, etc.) (see Figure 2).

2.2. Sub-stations

The same method can be used to determine the average cost of a sub-station as a function of its rating. Figure 3 shows the average cost of exchange sub-stations (primary and secondary circuits separated by a high - (180°C) or low - (110°C) pressure exchanger). The flowchart for this type of sub-station is given in Figure 4. It can be seen that the specific cost of these sub-stations increases sharply as rating decreases (particularly below 500kW).

3. EXAMPLE OF THE RESULTS OF THE COMPUTER PROGRAM

The example given below concerns a distribution network for 90 000 standard housing units with gradual connecting-up of the elements of the circuit (Figures 5 and 6).

The main characteristics of the network are :

- (i) total length: 60 km;
- (ii) peak capacity: 440 MW;
- (iii) fluid: water under high pressure at 180°C/90°C;
- (iv) average rating of a sub-station: 800 th/h.

The results obtained from optimization of the network are shown in Figure 7.

It will be seen in particular that:

- (i) Optimum flow speeds range from 1 m/s (small-diameter pipe) to 2.6 m/s (large-diameter pipe);
- (ii) heat losses range from 4% in winter to 11% on average throughout the year;
- (iii) the electrical consumption for pumping is low compared with the amount of heat distributed (1%).

Pumping costs, however, account for a sizable proportion of the cost of distribution proper (see below).

The total specific investment is FF 430/kW and can be broken down as follows :

- (i) pipe network: 82%;
- (ii) pumping stations: 3%;
- (iii) sub-stations: 15%.

4. OPTIMIZATION AND COST OF NETWORKS

A number of general conclusions can be drawn from a systematic use of the computer program for different configurations of network by varying its size, form and technical characteristics (temperature of fluid, permissible loss of pressure head, method of covering heat demand by varying flow rate and temperature variables).

1. Optimization of network

- (i) The optimum value for the total loss of head in the circuit - which reduces the total investment on for piping and the pumping costs (cost of pumps and electricity for pumps) is extremely low. Since it is hence unnecessary to determine it exactly, larger diameters can be accommodate any increases in capacity (see Figure 8).
- (ii) The method chosen to regulate the amount of heat supply - which can involve varying a) the flowrate, b) the temperature, or c) both at once has a very significant influence on the annual utilization time of the circulating pumps; hence it affects the optimum value referred to above. It is obvious that more energy will be consumed by regulating at a constant flow rate irrespective of the heat load; however, it is not always easy to vary the flow rate (scattered appliances with widely differing off takes and variable-speed pumps) and some other imperatives such as the need to maintain a minimum temperature for some users may also be taken into account.
- (iii) Generally speaking, the relative shares of piping and pumping costs (80% for pipes and 20% for pumping) remain constant when pipes of optimum diameter have been used i.e. for a total minimum discounted cost.

The percentage of annual heat losses for a new network (logging in good condition) is about 10% of the energy distributed.

2. Network variables

- (i) The main factors which influence the cost of a network are the "thermal density" of connected appliances (aggregate rating of connected appliances per km^2) and the "network density" which reflects the length of the network required for a particular area (see Figure 9).
- (ii) The size of the area served (Figure 10) the effective temperature range of the heat-transfer fluid; however the initial and return temperatures are variables with a less marked influence.
- (iii) By increasing the number of heat sources (boiler plants, geothermal boreholes, etc.) to supply heat to a given area, the cost of a network can be greatly reduced as the requisite throughput capacity of the piping is reduced (Figure 12).

FIGURE 1 : COST PER LINEAR METRE OF NETWORK (STEEL/CONDUITS), CIVIL ENGINEERING WORK ($\bar{G}$) AND THERMAL EQUIPMENT ($\bar{T}$) EXCLUDING PIPE-LAYING COSTS (DISCOUNTED PRICES AS AT MAY 1978).

FIGURE 2 : COST PER LINEAR METRE OF URBAN NETWORK AT 1978 PRICES.

FIGURE 3 : COST OF EXCHANGE SUB-STATIONS (1978 PRICES)

FIGURE 4 : CIRCUIT OF HIGH-PRESSURE AND LOW-PRESSURE EXCHANGE SUB-STATIONS WITH SECONDARY OUTLET AT A CONSTANT TEMPERATURE OF 90°.

FIGURE 5 : MONOTONIC CURVE OF EFFECTIVE RATINGS

E/EF

FIGURE 6 : TREND IN HEAT SALES

DISTRIBUTION

HEAD PRESSURE (mm.CE) = 230 000.
 TEMPERATURE RANGE (C) = 40.
 TOTAL OUTLET LENGTH OF NETWORK (m) = 59 698.
 MAXIMUM POWER TAKEOFF (Th/h) = 381 010.
 LINEAR "THERMAL DENSITY" (Th/m/km) = 6 382.

NODE NO	EQUIVALENT FLOW RATE m ³ /h	TAKEOFF FLOW m ³ /h	SPEED m/s	HEAD LOS MM.CE	THERORETICAL DIAMETER mm	NOMINAL DIAMETER mm
1	4143.76	199.27	2.61	19458.	744.	750.
2	3238.17	99.71	2.34	8395.	684.	700.
3	355.66	291.32	2.01	50924.	233.	250.
4	233.35	68.93	2.69	30860.	165.	175.
5	2878.70	191.61	2.08	12750.	659.	700.
6	126.10	218.42	1.98	61724.	142.	150.
7	35.37	61.27	1.25	10347.	89.	100.
8	77.46	134.17	1.22	14307.	143.	150.
9	59.78	103.53	1.75	30999.	100.	110.
10	53.06	91.90	1.88	34920.	93.	100.
11	1535.55	84.53	2.17	8607.	497.	500.
12	1135.90	141.83	1.98	13383.	443.	450.
13	1370.78	49.78	1.94	4040.	480.	500.
14	55.35	95.88	1.96	39645.	94.	100.
15	92.94	160.98	1.80	41847.	131.	135.
16	470.25	667.02	1.36	37900.	335.	350.
17	73.04	126.51	1.65	29847.	113.	125.
18	1188.49	122.68	1.68	7483.	400.	500.
19	57.56	99.71	2.04	44587.	98.	100.
20	28.74	49.78	0.56	1238.	128.	135.
21	30.95	53.61	0.60	1546.	134.	135.
22	113.98	197.43	1.32	21090.	156.	175.
23	740.03	237.70	1.64	17156.	393.	400.
24	44.22	76.59	1.56	20208.	88.	100.
25	537.49	57.44	1.19	2187.	356.	400.
26	26.53	45.75	1.47	13321.	74.	80.
27	143.79	249.05	1.00	12051.	215.	225.
28	148.29	256.85	1.04	13219.	219.	225.

HEAT LOSSES (th/h) = 13834.
 PERCENTAGE OF HEAT LOSSES IN WINTER = 3.5.
 AVERAGE PERCENTAGE OF HEAT LOSSES = 11.3
 DURATION OF WORK (PIPING) (YEARS) = 2
 DURATION OF CONNECTION (WORK YEARS) = 10
 NOMINAL PUMPING CAPACITY (kW) = 3666.
 MAXIMUM HEAT RATING AT NETWORK OUTLET (th/h) 394843.
 TOTALDISCOUNTED INVESTMENT (m FF) = 189.6

FIGURE 7

FIGURE 8 : INFLUENCE OF PREMISSIBLE LOSS OF HEAD ON THE TOTAL DISCOUNTED COST OF DISTRIBUTION

S = surface covered

d = "thermal density" of appliances connected

ΔT = effective temperature range

δ = "network density" $\frac{\text{length}}{\text{surface}}$

H = network head loss

FIGURE 9 : INFLUENCE OF "THERMAL DENSITY"

FIGURE 10 : INFLUENCE OF AREA COVERED.

FIGURE 11 : INFLUENCE OF TEMPERATURE RANGE (OUTLET-INLET)

FIGURE 12 : INFLUENCE OF NUMBER OF SOURCES ON SPECIFIC INVESTMENT