USE OF LOW ENTHALPY GEOTHERMAL ENERGY FOR RESIDENTIAL HEATING

Jean LEMALE

Ademe - Délégation Régionale Ile de France, Tour GAN, Cédex 13
92082 Paris La Défense 2, FRANCE

Key words: district heating, distribution system, machinery, Paris region,

INTRODUCTION

Almost all the geothermal plants in France are associated with a heating network serving residential units and associated urban facilities. It is estimated that approximately 200,000 housing equivalents are at present connected to urban heating networks based on geothermal energy More than 80% of these are within the Paris region where a perfect set of conditions exists between an easily mobilized resource and a concentration of habitations of apartment dwellings.

Two scenarios are met with; either a heating network already existed before the introduction of the geothermal heating, or a completely new heating network had to be constructed to exploit the available geothermal energy In the first case it was necessary to make the existing network compatible with the constraints imposed by the temperature level of the geothermal supply. In the second case it was necessary to design a routing that best optimized the geothermal energy under acceptable economic conditions.

A number of the principles developed to bring about this optimization are presented here.

1. PRODUCTION PLANTS

Flow rate and temperature depend on the characteristics of the aquifer, the dimensions of the well and the method of exploitation.

The temperature of the resource is a function of depth and local temperature gradient. The temperature at the well head is a few degrees lower than that at the well bottom, and the greater the output, the smaller is this difference. The factors that determine flow rate are the transmissivity (the ability of a porous rock to permit fluid to flow through it) of the reservoir and the static pressure of the fluid. Where conditions are favourable, artesian exploitation is possible; elsewhere, or if a maximum flow rate is sought, then a submersible pump **is** installed. Well diameter also influences flow rate, for example, the difference in cost between the slightly more expensive 9 5/8" well and a 7" well is, in general, rapidly compensated for by an increased flow rate.

Raising the flow rate by pumping means higher electricity consumption. Plants working on a doublet system commonly require high levels of electric power, both at the production and the reinjection stages. Some examples of electricity consumption are shown in table 1. Theoretically, there should be a rise in power consumption during reinjection as the fluid temperature decreases, but in practice, the rise in fluid viscosity is compensated by the incresed weight of the water column in the well. The maximum flow rate is limited by technical constraints such as the drawdown in the production wells, and excessive pressure during reinjection. The size of the pumping system will be at an economic optimum between the rise in pumping costs and the amount of heat recovered (figure 1).

Table **1** - Examples of electricity consumption

	Alfortville	Epinay/snrt	M.Alfort 1	M.Alfort 2	CACHAN 1	CACHANZ	ORLY 1	ORLYZ	*Mean*
Nominal flow rate (m3/h)	270	250	300	250	180	180	110	250	*223,75*
Temperature (°C)	74	73	72	72	68	68	74	250	*93,88*
Pump system	submersible	submersible	submersible	submersible	submersible	submersible	artesien	turbo-pump	
Elec cons. P (MWh)	250	245	510	320	510	440	60	460	*349,38*
Elec cons. loop (MWh)	1250	1600	2900	1800	2350	2350	500	2400	*1893,75*
Geo.ener (MWh/yr)	46000	50000	41000	34000	22500	22500	23000	34000	*34125,00*
MWh geo/MWh elec	36,80	31,25	14,14	18,89	9,57	9,57	46,00	14,17	*22,55*

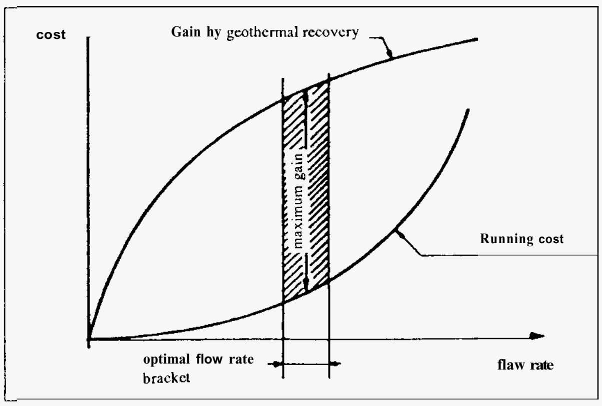

Fig. 1 - Maximisation **of well** output

2. TYPE OF USE

The essential qualities of a good consumer of geothermal heat are return temperatures as low as possible and a maximum annual length of utilization at nominal power.

2.1. Space heating

The use of geothermal energy for space heating is conditioned by climate, and obeys the rules described below

In order to provide a given quantity of heat to **a** room at **a** given temperature, the heat transmitters require various temperature levels according to their size Figure **2A** shows the temperatures of heat-carrying fluid in radiators and floor panels at the inlet and outlet of the transmitter as a function of external temperature The lines representing temperature regulation have a common origin, the abscissa point of **17°C** external temperature above which heating is regarded as unnecessary

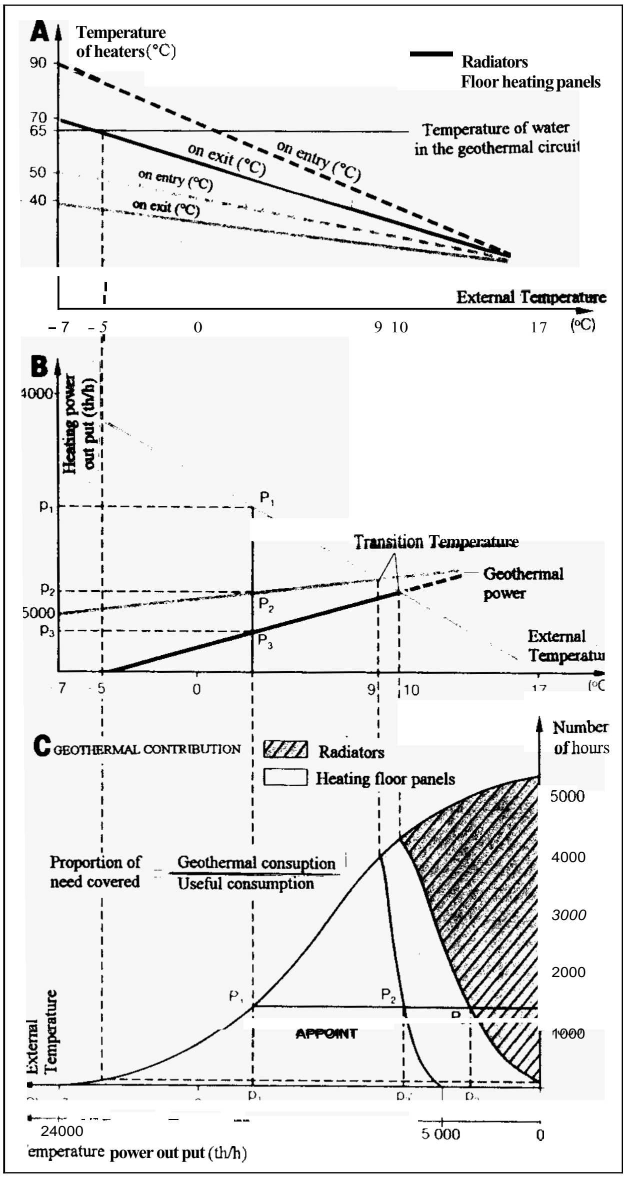

Fig. 2 - Determination of coverage.

In the case where the temperature of geothermal water at the exchanger outlet is 65°C, it can be seen that this temperature is insufficient to supply radiators so long as the external temperature is no higher than 1°C, and that it is totally ineffective when the external temperature is lower than -5°C. Where the premises are fitted with floor panels, a geothermal water temperature of 50°C is sufficient for an external temperature of -7°C. The heating demands for premises in a type-operation, shown in figure 2B, are represented by a straight line through the points representing zero (17°C) and maximum (lowest temperature = -7°C for the Paris area) demands.

The effective power provided by geothermal energy is a linear function of flow rate and the difference in temperature between outlet and return. The example given in figure 2B has a

flow rate of 200m³/h, the power provided by geothermal energy can be expressed by the formula:

$$P_{MW} = \frac{4.18}{3600} Q_{(m3/h)} \times \Delta T_{(°C)}$$

$$Q = 200_{m3/h}, \quad AT = 65\ °C - T°_{Return}$$

The intersection of these lines with the line representing the heating requirements defines the transition temperature (the external temperature below which geothermal energy is no longer adequate to meet the power demand). In this example, the temperature is 9°C for floor panels and 10°C for radiators. These graphs clearly show that the lower the external temperature (once it is below the transition temperature), the lower is the power provided by geothermal energy.

To evaluate the annual amount of energy that could be provided by geothermal energy for space heating, a monotonic curve is used. The monotonic curve in figure 2C shows the cumulative frequency of average daily temperatures. In the given example, the external temperature is statistically below 12°C for 4700 hours. Each external temperature corresponds to a level of heat requirement, given directly by graph 2B. Using this new abscissa scale, the area delimited by the monotonic curve represents the total energy consumed during a season of heating. The areas corresponding to energy provided by geothermal energy are determined in the same way. In the given example, geothermal energy covers 35% of the needs where the heating system is supplied by radiators alone, and *60%* where floor panels are used.

2.2. Provision of domestic bot water

The production of domestic hot water by geothermal energy is a particularly attractive application:

- Unlike heating, the needs exists throughout the year
- The temperature of the water distributed (between 50 and 60°C) is generally compatible with the temperature available from geothermal energy.
- The temperature of municipal water between 8 and 15°C makes possible a large difference in temperature.

However, the random level of drawing on the system can lead to high demands which may necessitate large storage systems.

3. ORGANIZATION OF THE DISTRIBUTION SYSTEM

3.1. Back-up and emergency

For economic reasons, geothermal energy is never used to meet the total demands of residential heating in France. It can be seen on the monotonic curve that with 50% power at -7°C, geothermal energy covers more than 80% of the requirements. In addition, as geothermal resources can be unreliable due to breakdown or other reasons, a combination of a traditional heat production system and the geothermal heat production system is generally used. This consists of one or more boiler plants that are used to ensure the supply not covered (back-up), as well as the total demand in the case of resource unavailability (emergency). These back-up and emergency systems, which only have to run for a limited number of hours, are based on low capital-cost systems, commonly oil-fired boiler plants, sometimes gas if the running time is sufficient (figure 3).

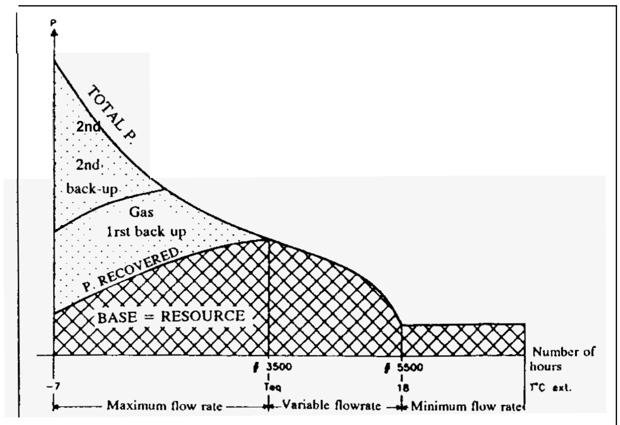

Fig. 3 - Monotonic curve

Several possibilities exist for back-up heat supply:

Central back-up (figure 4)

Central back-up **is** the most commonly used system with a single plant that supplies the total input to the network. It may consist of several boilers which run on different **types** of fuel such as gas for back-up and fuel oil for emergency. This option allows the best technical and economic management of the system **as** a whole. However, it requires a relatively **high** investment plus the availability of ground for construction of the plant close to the site of resource exploitation

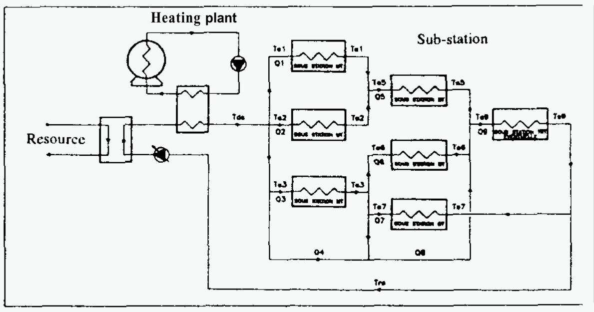

Fig. 4 - Central back-up, cascade of sub-stations.

Local back-up (figure *5)*

Another system is based on retaining the boiler plants of existing units connected to the network. The heat network supplies heat based on geothermal energy, and each subscriber provides his own emergency back-up. This option has the advantage of requiring only a limited investment, but optimal management **of** the network **is** difficult. It **is** not recommended apart from specific cases of connecting existing units with a limited number of heating plants.

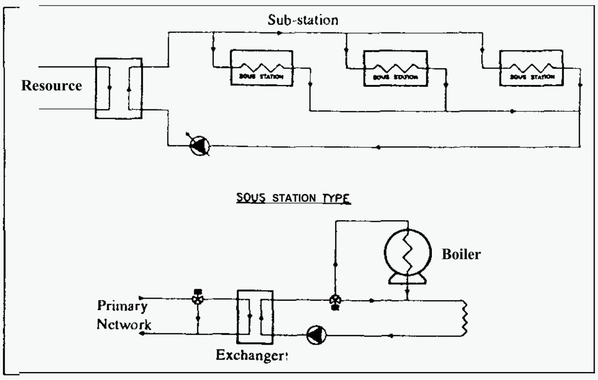

Fig. 5 - Local back-up

*Semi-central **back-up*** (figure *6)*

Certain sites have several large boiler plants, generally with greater capacity than necessary for the units they supply. One plant, for example, could be used in priority, and the others used in turn on coldest days. The solution adopted will depend on the context of the project envisaged, in particular, the type and adaptability of existing heating plants, and the calculation of economic optimization.

3.2. The temperature cascade

Generally, geothermal projects are applied to existing units heated using either radiators or floor panels. It is necessary to determine the optimal system of connecting these units so as to obtain the lowest possible general return temperatures from the network.

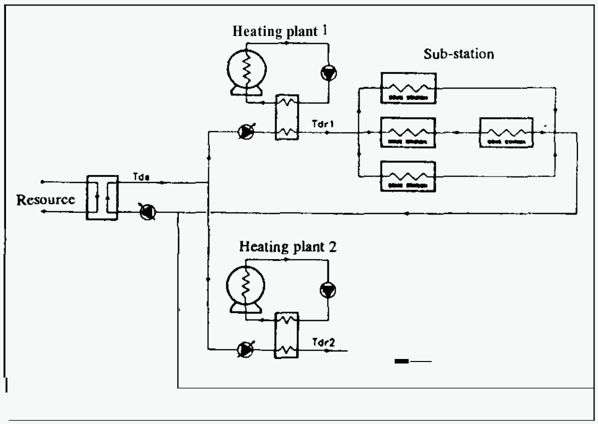

Fig. 6 - Semi-central back-up

Figure **2A** shows that return temperatures from the buildings equipped with radiators are higher than for those with floor panels. Wherever possible, the "hot" returns are used to supply the low-temperature plants via a series of connections; this is **known** as a "temperature cascade" (figure **7).** The, "low temperature" sub-stations which supply the buildings equipped with floor panels, are, in addition, fed by a three-tube circuit:

- MT (medium temperature) input from the upstream sub-stations, which supplies the radiator-equipped buildings.
- HT (high temperature) input directly from the primary network, used when the output of the upstream sub-stations is insufficient
- Common return to the primary exchanger.

Studies for the establishment of cascades must take into account the geographical location as well as the nature and power of the heat transmitters of the units to be connected. The final choice of configuration is made after comparison of the various possibilities of network paths. Computing facilities and appropriate software are generally indispensable.

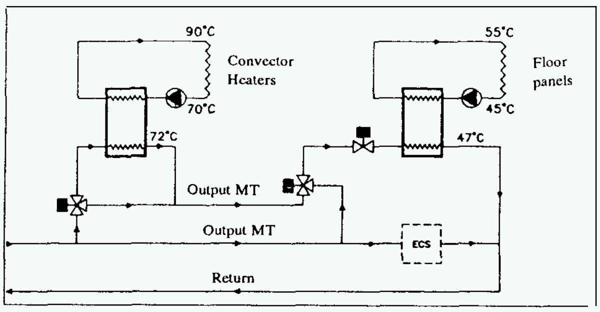

Fig. 7 - Connection of two sub-stations in the cascade.

4. EXPLOITATION

4.1. Heat exchanger output

The geothermal heat is supplied to the network via one or more heat exchangers The aim is to obtain a discharge temperature (pnmary outlet = Tsp) that is as close as possible to that of the return from the network (Trs) To achieve this, the secondary flow rate used is slightly greater than the pnmary flow rate

The heat exchanges at the exchangers are governed by the equation given below, as illustrated in figure **8**

$$Qp*(Tep-Tsp) = Qs*(Tss-Tes).$$

If the primary flow rate (Qp), is greater than the secondary flow rate (Qs), then the thermal balance does not improve, but as the flow rate Qp increases, the discharge temperature (Tsp) rises On the other hand, if Qs is greater than Qp, Tsp remains near the return temperature from the network (within the range of the temperature squeeze), but the temperature at the secondary outlet (Tss), falls.

Experience on geothermal projects has shown that optimum recovery is acquired with a secondary flow rate IO-15% greater than the primary flow rate.

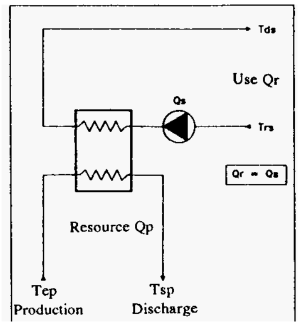

Fig. 8 - Direct recovery by the exchanger

4.2. Operation and regulation (figure 9)

The transitional temperature (Teq), is defined as the temperature above which it is possible to meet the full energy demand from geothermal energy Below this external temperature, the flow rate is at its maximum and constant, and power increase is obtained by varying the initial input temperature to the network

Above the transitional temperature, the input temperature remains constant at a level corresponding to the characteristics of the resource, the flow rate varies as a function of demand The demand could be satisfied with a constant flow rate, but in this case, the return temperature rises gradually as the demand falls Modulation .the flow rate further has the advantage of reducing the global ectricity consumption for pumping

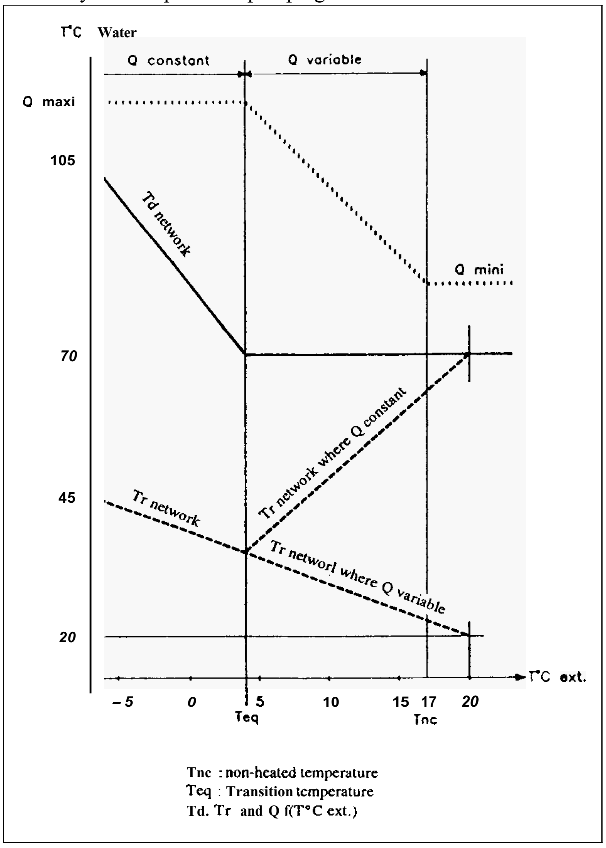

Fig. 9 - Maximisation of **well** output

4.3. Running of the plants

The running of a geothermal plant is always aimed towards the search for the lowest possible temperatures whilst, obviously, meeting the users needs satisfactorily.

The running **of** a plant demands:

- verification of temperatures and flow rate of each primary network at the start of the production centres and at the main substations;
- pursuit and display of curves for optimum control, and immediate application of necessary corrections in the case of a diversion;
- comparison between real energy results and theoretical data.

The installation of a remote-management system is essential for the efficient operation **of** a plant.

5. SPECIFIC EQUIPMENT

5.1. Exchangers

The need to obtain the smallest possible difference between the primary and secondary temperatures (approach temperature of the order of one degree) nearly always requires the use of plate exchangers. In the case of sub-stations for appartment buildings, the technique of transfemng heat by mixing, albeit more efficient from an energy point of view, is generally avoided for reasons of hydraulic equilibrium.

As the surface area of the exchanger increases, so the temperature squeeze decreases. The dimensions of the exchanger, therefore, are derived by an economic study comparing the cost and energetic performance for several surface values. The choice of material will be governed by the physico-chemical characteristics and temperature of the fluid.

In standard hot water networks stainless steel plates are used with nitrile seals where the temperature is below 95°C, or EPDM seals where the temperature may exceed 95°C.

Where geothermal exchangers are in direct contact with the fluid from the subsurface, which is commonly highly corrosive, titanium plates are used.

5.2. Piping

The piping of the heating network may be installed in gutters or ground pipes. The need to keep costs down has led to the use of the latter alternative. Materials used for the piping are:

- standard black steel;
- epoxy resin and glass fibre (temperature limit, I10°C);
- reticulated polyethylene (temperature limit, 80°C, and limited pressure);
- insulated cast iron (manufacture ended in 1989).

The insulators used are polyurethane or polyethylene foam, and in places, rigid epoxy foam. These are protected by a casing of high density polyethylene (HDPE), which is waterproof and provides an anti-corrosion barrier against attack by the soil for the iron pipe.

5.3. Circulation pumps

Water circulation in the networks is maintained by variable-speed centrifugal pumps.

Pump specifications are determined from the flow rate and manometric head by calculation. The most reliable and economic way of obtaining variations in speed is by using asynchronous motors driven by frequency variators.

6. HEAT PUMPS

Heat pumps make possible an increase in the power of geothermal stations by lowering the temperature of the water reinjected in the well. This is only advantageous where the economics of the project improve with the use of heatpumps rather than with an exchanger alone.

The heat pumps must in no way be regarded as a back-up system to the geothermal exchange, but as an associated system. In order for the heat pump to be profitable, it must be run for a sufficiently long time and be adaptable to electricity prices.

Several connection possibilities exist according to the location of the evaporator and the condenser.

Examples of three types of set-up are given below.

• Condenser in **series with** exchanger (figure 10)

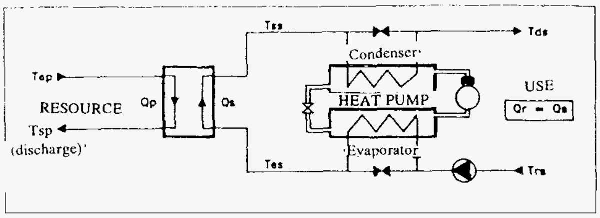

Fig. 10 - Recovery **with heat pump** (condenser **in series).**

The evaporator is located on the return pipe from the network, before the geothermal exchanger, and the condenser at the secondary outlet before the back-up boiler It is equally possible to place the evaporator on the discharge or reinjection geothermal network This set-up makes it possible to increase the temperature Tss at the secondary output from the exchanger if it is too low

• Condenser in parallel with exchanger (figure 11)

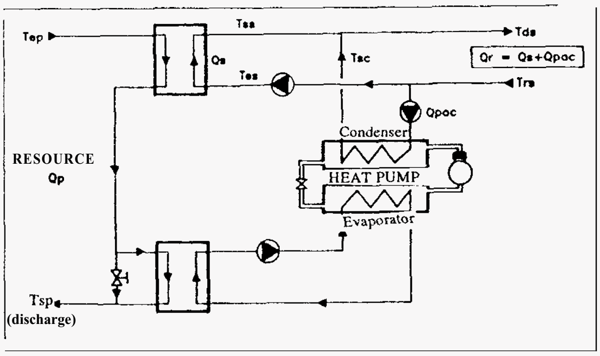

Fig. 11 - Recovery **with heat pump** (condenser **in parallel).**

The evaporator is connected to the geothermal water discharge circuit, which, in general, necessitates a double exchange The condenser heats part of the flow of the network's return circuit and reinjects it into the output circuit This set-up enables a decrease in the discharge temperature and thus an increase in the available power of the network through the additional flow rate of the condenser

• Setting up a multiple heat pump system (figure 12)

The set-up shown in figure 12 illustrates the advantage of using where possible several small heat pumps rather than one alone. With a decrease in the temperature difference between the evaporator and condenser, the performance coefficient of a heat pump increases. The three heat pump set-up in "reverse series" provides significant benefits.

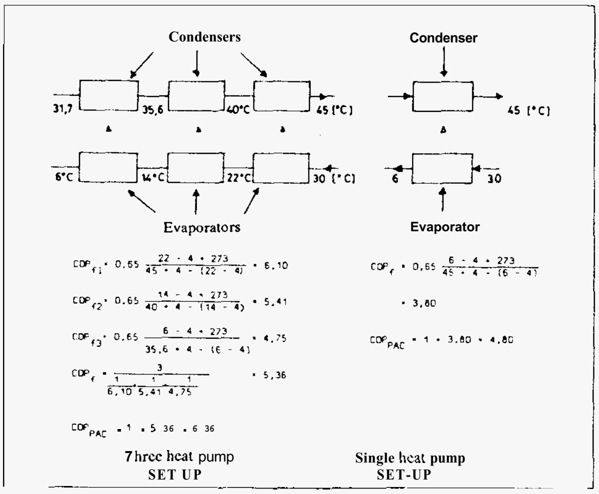

Fig. 12 -Setting up a heat pump in reverse series (Source plan Construction - Comite geothermie)

CONCLUSION

The economic performance of a geothermal project is obviously linked to the quality of its resource, but it is also in large, linked to the planning and the running of the surface equipment The best solution is only achieved through optimization, not only at the planning stage but also dunng exploitation

Constant control of exploitation, in particular by means of a remote-management system, ensures the best results. It should also be noted that a geothermal project is rarely inalterable, new users may appear, environmental conditions may change. Whatever the case, it will be necessary to adopt the best configuration by using to the maximum the experience and know-how of the professionals of the geothermal industry.