INTERNATIONAL SUMMER SCHOOL on Direct Application of Geothermal Energy

Under the auspice of:
Division of Earth Sciences

Chapter 2.7

GROUND-SOURCE HEAT PUMP IN FRANCE IN THE RESIDENTIAL

C. Olivier

EDF – Research & Development

1 – Heat pumps in the residential market in France

1 - 1 VIVRELEC's solutions - promotion of the HEAT PUMP by E.D.F.

For the last four years now, E.D.F. has adopted a policy of promoting heat pumps within the framework of VIVRELEC solutions.

VIVRELEC is a set of electrical heating solutions proposed by E.D.F., and implemented by partners having made a quality commitment.

These technical solutions, proposed in the new residential housing sector, meet a number of customer needs or demands. Heat pump solutions, considered to be "top of the range" solutions, are proposed within the framework of VIVRELEC, to provide either heating alone, or so-called '4 seasons' comfort providing both heating and cooling.

The launching of VIVRELEC in 1997 redynamized the development and the market of these products. Indeed the heat pump market in the residential area in 1997 represented about 1 500 to 2 000 installations a year. At the current time, it is estimated that some 10 000 heat pump installations will be made in 2001 (90% of which within the framework of the VIVRELEC programme). The market growth will be more than 20% in relation to the number of installations made in 2000.

1 - 2 – Heat pump-based energy and environment policy

Heat pump heating systems for residential sector have notable advantages:

- Use of the free, renewable energy present in the air, ground or water,
- Considerable power efficiency which will be able to be considerably improved further in the years to come, notably through a global quality policy,
- Low environmental impact (compared with conventional heating means),
- Effective contribution to combating the greenhouse effect.

Heat pumps in the new and existing residential sector are notably promoted within the framework of an agreement between E.D.F. and A.D.E.M.E. (Agence de l'environnement et de la Maîtrise de l'Energie, an organization supervised by the French Ministry of Industry and Research).

The purpose of this partnership, initiated at national level, is to develop and promote quality heat pump installations. Broken down at local level within French regions, this agreement forms the subject of a considerable amount of work such as the carrying out of "reference houses" accompanied by energy monitoring. This work in partnership makes it possible to progress together and position these systems in environmental terms.

1 - 3 – The systems available on the French market

A fairly wide range of systems are available in the residential sector. The diagram below shows the various existing techniques.

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Figure 1: Existing heat pump systems

Certain trends are already emerging differing from one French region to another. Air–to-air heat pumps are thus being developed faster in the South of France, while water-to-water heat pumps are more prevalent in the East of France and air-to-water heat pumps in the West. This distribution is principally related to climatic conditions and customer requirements.

It is estimated that 45% of machines are air-to-water heat pumps, 25% are air-to-air heat pumps and 30% are ground-source heat pumps (water-to-water heat pump with close and opened loop in the ground, direct expansion ground-coupled heat pump with fluid only in the ground or fluid in the ground and in the floor). The three types of ground-source heat pump (G.S.H.P.) available on the market are shown below.

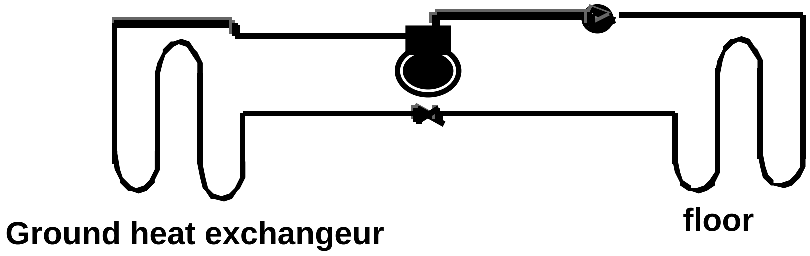


Figure 2: Direct expansion ground-coupled heat pump with refrigerant in the ground and in the floor.

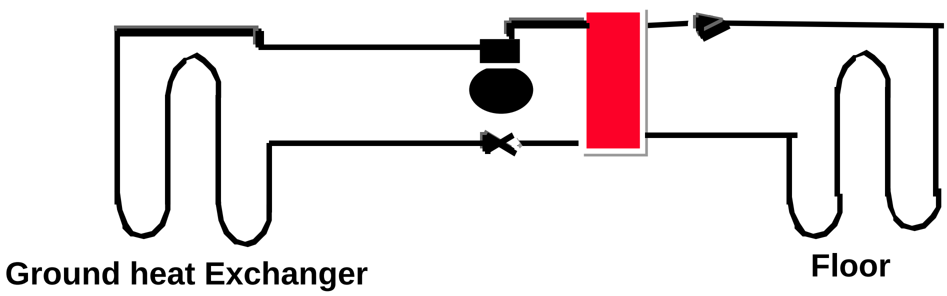


Figure 3: Direct expansion ground-coupled heat pump with refrigerant in the ground and water in the floor.

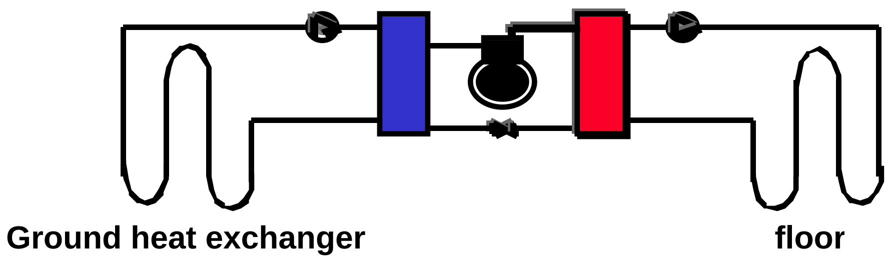


Figure 4: Ground-coupled heat pump with glycoled water in the heat exchanger and water in the floor.

2- Ground-coupled heat pumps in the residential market in France – Work carried out by E.D.F.

2 - 1 Increase in E.D.F.'s R. & D. expertise in support of VIVRELEC solution

The launching in 1997 of VIVRELEC solutions called for the development of reliable, high-performance thermodynamic solutions for heating, heating/cooling and heating/air conditioning.

To accompany the development of these solutions, it was decided to build up expertise in various thermodynamic systems including ground-coupled heat pump (G.C.H.P.) coupled to horizontal or vertical heat exchangers.

For these geothermic systems, the work was carried out in several stages:

- laboratory test on G.C.H.P. and various types of ground heat exchangers,
- starting up of vertical G.C.H.P. "reference houses",
- working out of technical rules for thermodynamic systems with horizontal and vertical heat exchangers,
- extension of operations over the French territory with vertical exchangers.

2 - 2 Setting up of "natural climate" test platform

The initial work carried out on G.C.H.P. involved setting up a ground heat exchanger test platform on the Renardières site (R.&D. site). This platform allows the heating and cooling needs of a house to be simulated according to the site climatic conditions. To reproduce the thermal response of the heating installation of a detached house, the inertia of the heating system had to be simulated and the energy evacuated in accordance with a law varying as a function of the outside air temperature and the house's insulation. Thermal inertia was provided by inserting a 500 litre tank in the hydraulic system. Energy was evacuated by plate heat exchanger and an air cooler.

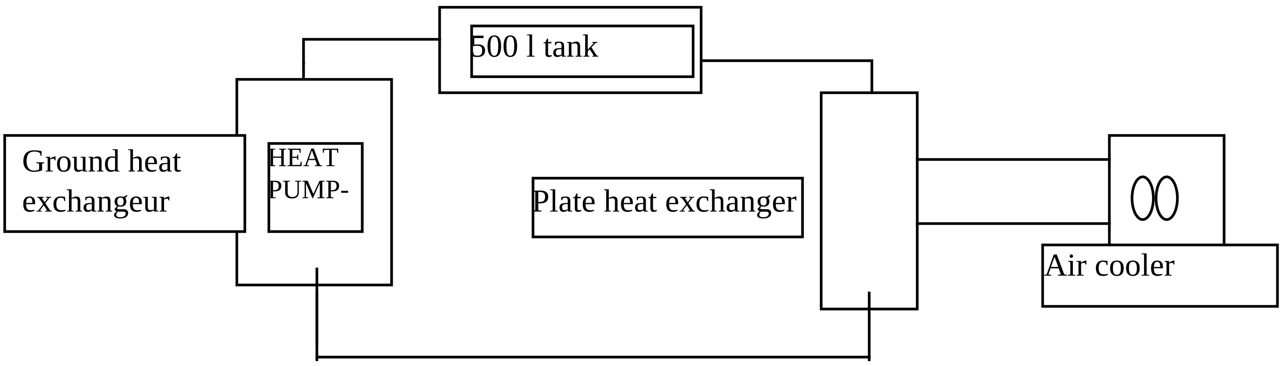


Figure 5 : Platform operation schematic diagram

The objectives of this platform were to:

- compare the various technologies and existing horizontal and vertical heat exchanger configurations,
- verify heat exchanger sizing rules,
- assess the performance of machines and the effect of auxiliary equipment (circulators),
- determine the variation over time of ground temperatures.

In view of the various techniques encountered on the French and overseas market, it was decided to install six ground heat exchangers in all:

- one SOFATH process direct expansion heat exchanger

- one SOLTERM process glycoled water heat exchanger in the stripped topsoil
- various glycoled water exchangers in 4 - and 6 - pipe per trench
- one SLINKY process glycoled water spiral exchanger
- one vertical heat exchanger.

Various models of G.C.H.P. were tested. The models were of French, Swiss or Austrian origin.

After three years of operation of the platform, the main results obtained are as follows:

n for horizontal heat exchangers, the performance of the system (water-to-water heat pump + ground heat exchanger) basically depends on the heat pump performance and not on the type of ground heat exchanger used,

n the seasonal coefficient of performance (C.O.P) during the heating period varies from 3.6 to 3.9 for heat pumps marketed in the French market and reaches 4.8 for heat pumps marketed in the Swiss market. By comparison, an outside air heat pump installed on this platform provides a seasonal coefficent of performance of 2.5,

n for all the tested systems, the ground regeneration is rapid as at the end of the heating season, the ground temperatures in the vicinity of the various heat exchangers are equivalent to those of the reference ground. During the winter, however, the ground was seen to freeze around the heat exchanger for a period of fifteen days or so (rain rapidly regenerated the ground).

These platform tests made it possible to obtain the actual performance of this type of system. The results obtained also demonstrated to companies that the use of a glycoled water heat exchanger does not degrade the performance of the system as compared with a direct expansion system. Indeed, the head loses in the cooling circuit and the pressure fluctuations compensate for the performance degradations due to an additional heat exchanger.

This platform continues to operate at the present time but its use has been slightly modified. Initially system oriented with ground heat exchangers, it now also allows various air type heat pump systems to be tested (outside heat pump and ducted heat pump). For these latter systems, the seasonal performance of machines was also analyzed but more especially their control and the command of the auxiliary electric backup. For the G.C.H.P. , we are continuing to monitor the variation over a time of several years of the ground temperature in the vicinity of the vertical heat exchanger. Other work includes the qualification of new water/water machines notably using HFCs and free-cooling tests on the vertical heat exchanger during summer periods.

2 - 3 Carrying out of vertical G.C.H.P. "reference houses"

Unlike heat pumps using horizontal ground heat exchangers which are relatively well known by installers or contractors, the initiating of "reference houses" for vertical heat exchangers within a controlled technical framework proved to be essential notably on account of the lack of expertise in the boring field.

Although the horizontal heat exchanger met the expectations of customers well, the terrain area is not sufficient to perform the installation in 30% of cases, according to the main players. The vertical heat exchanger solution thus appears to be potentially advantageous for setting up a sector in the French market.

In all, some fifty or so detached houses were build in the East of France (Rhône-Alpes, Franche-comté and bas-Rhin) and in the West of France (Brittany), with financial aid to promote the development of this technique. To carry out these "reference houses", the boring specialists involved were of foreign origin (Swiss boring specialist having set up a branch in France) or boring specialists having acquired expertise through collaboration with Swiss or German boring specialists. For each "reference houses", E.D.F.'s R.&D. division provided technical support for E.D.F.'s negotiators and sales representatives during the customer negotiation file setting up phase, and for the verification of compliance with the implementation rules of the whole installation (borehole, vertical heat exchanger, heat pump sizing, floor sizing, etc.).

The experience acquired demonstrates the interest of this type of technology for the French market. The 50 houses were quickly found. The advantage of this technique obviously lies in its "top of the range" image and its "ecological" character but also in its low operating cost.

The setting up of these 50 "reference houses" made it possible on the one hand to develop this technology for the French market and on the other hand to determine and exercise control over deployment problems. One of the confusions most often encountered relates to the vertical heat exchanger sizing. While the ratio of 50 W/m is known, it is very often incorrectly applied. The capacity taken in some cases is not the capacity on the evaporator (ground heat exchanger) but the capacity on the condensor (floor).

We also encountered several problems in terms of borehole and heat exchanger implementation. The filling of the hole with glycoled water is not well controlled. Some fill the hole with water and then antifreeze whereas a homogeneous mixture in the hole must be obtained in two stages: during the first stage, the water present in the hole is pushed with the air and during the second stage, the hole is filled simultaneously with water and antifreeze (water-antifreeze solution) via a mixing tank.

The connections used between the borehole head and the house do not guarantee the durability of the installation and in many cases no inspection hatch was installed at the level of the borehole head.

The borehole was filled with a mixture of cement/bentonite but in proportions not constant according to the "reference houses' (the proportions of 90% of cement and 10% of bentonite given in some documents are not adapted – a higher proportion of bentonite is required). The first boreholes were filled almost entirely with cement and the composition was then modified to provide much more resilient mixtures also providing better heat exchange with the ground.

A few "reference houses" failed. For example, the boring in a pressurized artesian layer did not make it possible to consolidate the borehole walls thereby bringing about the failure of this "reference houses". Another borehole initially made for vertical G.C.H.P. was converted into a an installation of groundwater heat pump due to the presence of a considerable quantity of water.

While it was not difficult to locate these sites, the setting up of the various installations was fairly long. As a consequence, few items in terms of lessons learned are available for the time being. Globally speaking, there has been no bad reference.

The initial indications on site confirm the competitiveness of these installations in terms of operating cost. Indeed, in the East of France, the heating bill for systems with vertical heat exchangers is 2.6 Euro including taxes per square meter.

The table below provides a rapid comparison of the investment and operating costs between various types of systems associated with a heating/cooling floor.

	Investment cost (Euro including tax /m^2)	Operating cost (Euro including tax /m^2)
Vertical ground-coupled system	137	2.6
Horizontal ground-coupled system	115	2.6
Air-to-water heat pump	92	3.8

Table 1: Comparison of the costs of various production systems for a heating / cooling floor application

While the heating bill is highly competitive, it should, however, be noted that the investment cost for this type of installation remains high. This is due to the boring cost which is currently estimated to Euro 38 - 53 plus tax per linear metre of boring.

2 - 4 Establishing of rules

Since the launching of thermodynamic solutions and as a result of the difficult experience encountered at the beginning of the 1980s (PERCHE operations – boiler coupled with heat pump), it has, from the launching of VIVRELEC, appeared essential to establish rules for implementing thermodynamic systems in houses and blocks of flats. A Heat Pump Commission was thus set up at E.D.F.'s initiative in 1998, within the Association Française du Froid (French cold society) to work out technical guidelines for the whole sector (design offices, installers, etc.). This Heat Pump Commission includes the different partners in the heat pump market and notably established the following rules for implementing geothermal installations:

- glycoled water-to-water thermodynamic systems, mainly covering installations with horizontal heat exchangers (P/N G.E.D.O. 1.15.B.20/98),
- glycoled water-to-water reversible generators – heating or heating/cooling floor – vertical ground heat exchangers (P/N G.E.D.O. 1.11.B.02/00).

These guides describe the different points to design and install heat pump. The following subjects are detailed:

- description of the designed system: location of the various components, operating mode,
- reminder of current standards and regulations: electrical safety and other safety aspects, test standards, technical specifications, acoustics, refrigerant, etc.,
- sizing: heat pump, auxiliary electrical system (electrical backup), emitter (heating and cooling, etc.),
- minimum technical criteria for the heat pump: coefficient of performance, energy efficiency ratio, operating limits, etc.,
- recommendations to implant heat pump,
- sizing of hydraulic pipes,
- recommendations for implementing hydraulic pipes,
- main control functions,
- minimum rules for the implementing and maintenance of installations.

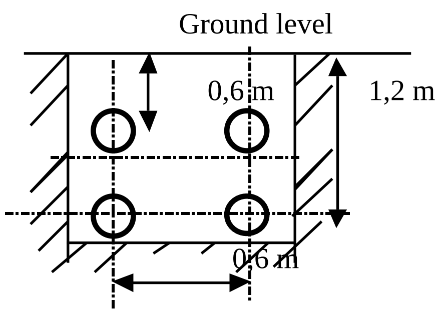
The technical rules are derived from the experience of manufacturers, the tests carried out on the "natural climate" platform and lessons learned on "reference houses". These guides are designed for heating floor or heating/cooling floor installations.

2 - 4 - 1 A few examples of specific rules for the horizontal heat exchanger

The guide describes the various possible horizontal heat exchanger configurations;

- 4 - pipe per trench,
- 6 - pipe per trench,
- stripped topsoil.

The choice of the configuration type will depend on the terrain area available. Indeed, stripped topsoil configurations call for more space than configurations in trenches. All the configuration that can be produced are shown below.

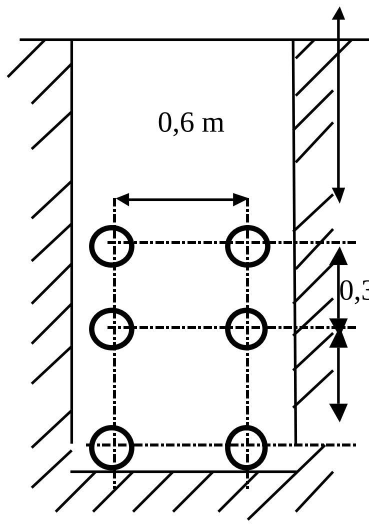


Figures 6 : 4 -pipe configuration

level

m

m



Figures 7 : 6 - pipe configuration

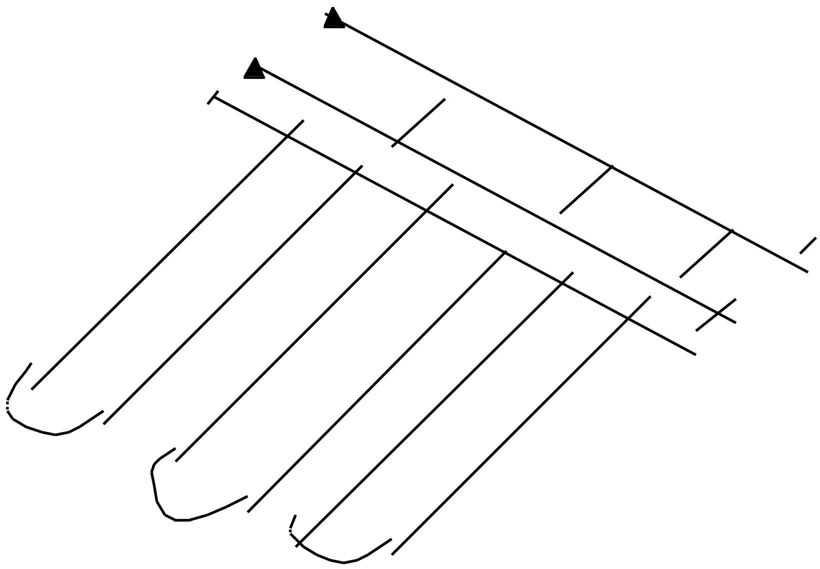


Figure 8: Example of a horizontal heat exchanger installed after topsoil stripping

The implementation of each of these configurations must comply with rules for the minimum spacing between the pipes and horizontal trenches given in the table below .

Horizontal configurations		Horizontal spacing between pipes (m)	Vertical spacing between pipes (m)	Centre-to-centre spacing between two trenches (m)
Stripped topsoil		0.4	-	-
4 - pipe per trench	Square tubes	0.6	0.6	1.2
6 - pipe per trench		0.6	0.3	1.2

Table 2: Minimum spacings between pipe and trenches

The table below indicates the maximum powers that can be extracted per metre of tube and per square metre of terrain with a glycoled water temperature of - 5 °C and a heating/cooling floor application (water conditions 30/35°C)

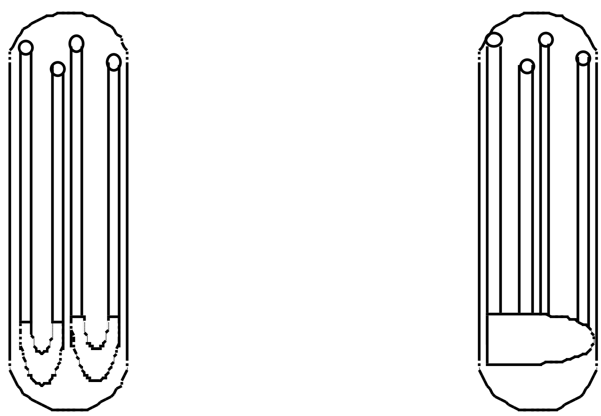
Configurations	Max. capacity extracted from the ground = Heating capacity – compressor power			
	Per metre of tube [W/m]		Per m3 of ground [W/m3]	
	Tbase < - 10 °C	Tbase >or=- 10 °C	Tbase < - 10 °C	Tbase >or= - 10 °C
Stripped topsoil	12	15	30	37
4 - pipe per trench	11		37	
6 - pipe per trench	8		40	

Table 3: Maximum capacity extracted from the ground

2 -4 -2 A few examples of specific rules for the vertical heat exchanger

In terms of regulations, it should be recalled that any borehole made at a depth in excess of 10 m must be subject to a boring declaration made to the D.R.I.R.E. (Direction Régionale de l'Industrie, de la Recherche et de l'environnement) of the region before the work begins.

Vertical heat exchangrs should be of the ‘double U-tube’ type. The 4 pipes can be connected together (common chamber) or in pairs to the base as illustrated in the figure hereafter.



Separate double U-tube *Common chamber*

Figure 9 : Two types of vertical heat exchangers

The main types of materials used are high- and low-density polyethylene (PEHD - PEBD). The nominal diameter of the pipes used for the heat exchangers are 25, 32 and 40 mm with a nominal operating pressure of 2.5 bars (12.5 bars at the bottom of U-tubes for a length of 100 m).

The minimum spacing between holes must be at least 10 m. Minimum distances must also be observed with regard to obstructions present on the terrain (trees, buried networks, etc.).

With regard to the sizing of vertical heat exchangers, it should be recalled that the sizing must be determined rigorously as any under sizing will lead to irreversible ground thermal depletion, degraded performance and powers let down over time.

In general, the heat exchanger is sized in heating mode on the basis of a capacity let down to a maximum of 50 W/m of vertical boring (evaporator capacity = condenser capacity – compressor power). It should also be checked that the sizing does not lead to energy in excess of **100 kWh/m/year** being taken from the soil.

2 -5 Extension of vertical heat exchanger "reference houses" over the territory

As a result of the success encountered with the first 50 "reference houses", it was decided to initiate a second phase aiming to extend the market of this technical solution over the whole French territory. Several modifications and improvements were made to the initial program:

- the prime levels were significantly lowered,
- commercial arguments were developed on the basis of the analysis of initial customer feedback ("top of the range" image, ecology, low operating cost, etc.),
- it proved to be essential to bring for each partner the best technical and available information, by notably defining the operating scope and responsibilities of each partner (boring specialist and installer).

A considerable portion of the boring specialist's know-how lies in his knowledge of the data of the ground in his region. Local companies should thus be favoured wherever possible, especially as there is little financial incentive for boring specialists to travel any distance to sites. E.D..F.'s partner boring specialists thus sign agreements concerning the performing of boring, and the techniques and materials used.

The content of this agreement includes most of the key points observed when carrying out the 50 "reference houses".

The agreement may be of various types. Indeed, each boring specialist can work differently on the installation. Some provide the complete service (boring, heat exchanger, junction up to the heat pump), while others only bore the hole, install the heat exchanger and fill in the borehole. In all, there are thus three different types of agreements involving, according to the case, the boring specialist alone or the boring specialist associated with other professionals (installer, heat pump manufacturer). In all cases, the agreement letter stipulates:

- the boring specialist's geographic working area,
- the boring equipment and techniques used and available,
- the professional who designs the heat exchanger,
- the type of hole used (either a hole specifically dedicated to geothermic or a hole made by the boring specialist and validated by E.D.F.)
- the filling materials used - the borehole will be filled by injecting sand and gravel over the whole height where water will certainly be present over the long term – the borehole will be filled by cementing (cement/bentonite) over the remainder of the borehole - at least a plug of 10 at the top of the borehole must be do to prevent the layer being contaminated by surface water runoff,
- description of the manifold / boring head junction, i.e. specify whether the latter is realised with or without an inspection cover and if no inspection cover is provided for, note the need to fit heat welded or electrically welded polyethylene couplings,
- the part numbers of the monopropylene glycol placed in the hole to prevent freezing, etc.

This agreement letter includes the heat pump sizing rules, i.e. 80 to 120% of the home's losses, the obligation to make a boring declaration to D.R.I.R.E., the rules for locating the heat exchanger on the property (distance to be observed relative to items on the terrain) and the obligation to show the exact location of the heat exchangers and connections on the layout drawing.

Once the boring specialist's agreement has been made, the implementation of the vertical heat exchanger will, for each installation carried out within the VIVRELEC framework, call for the supplying of a data sheet on which the boring specialist and installer have entered the operations carried out thereby providing an indication of each partner's working scope and responsibilities.

To date, 4 boring specialists have been approved by E.D.F. to carry out operations within the VIVRELEC framework. Other contacts are in process mainly in the East, the West and in the Rhône-Alpes region. An initial contact has also just been established in the south.

During the second half of 2001, ten or so boring specialists will be E.D.F. partners and will thus cover a good part of the French territory.

Prospects

In the current situation, it is clear that the extension of "reference houses" over the French territory is not of any great consequence owing to an investment cost which is as yet high. Today, vertical G.C.H.P. represent about 200 installations with VIVRELEC. While the heat pump market is developing G.S.H.P., heat pumps as yet only concern a tiny portion of customers. This remark is available for G.S.H.P. and heat pump in general.

However, on the assumption that the French market has a development capability on the scale of the Swiss, Swedish or US markets, the growth potential is very high. For this purpose, we will need a strong promotion policy bringing together all those involved and communication aimed at the general public. However, in spite of this considerable as yet untapped potential, it can be seen that France is already in 3rd position in Europe behind Sweden and then Switzerland, in terms of the number of heat pumps sold.

From the environment standpoint, the development of heat pumps, for the heating of homes, may contribute, in conjunction with other measures, to meeting the commitments made within the KYOTO protocol by limiting the CO2 emissions of conventional fossil fuel heating systems.