

TESTS AND SIZING OPTIMIZATION OF COMPACT COLLECTORS FOR GROUND SOURCE HEAT PUMPS

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Abstract: Ground Source Heat pumps (GSHP) have a fast growing success in Europe, but only in new residential houses. The main barriers for the development of GSHP on the retrofit market are linked to ground collectors, due to installation costs and needed area in gardens.

The compact collectors of IVT were developed to overcome these barriers, especially reducing installation costs. Compact collectors are commercialized in Sweden and UK but are unknown in France, where the development of GSHP on domestic retrofit market is a major stake. Compact collector systems in Sweden are associated with an exhaust air auxiliary system for reloading and for reducing the number of collectors.

This paper describes two field tests of compact collectors, run in France, with special test conditions taking into account french retrofit market characteristics. This paper analyzes the installation process and sizing and the seasonal performances of both systems.

Then, this paper presents the results of a software, developed for EDF, which sizes GSHP systems. Tests and design results are compared and analyzed.

The main result is that the vertical installation of compact collectors provides high seasonal performances, with a sizing equivalent to an horizontal installation. However, the installation process is, for the moment, hardly adapted to the french retrofit market constraints.

Key Words: *Ground Source Heat Pumps, compact collector, field tests, sizing, retrofit market*

1 INTRODUCTION

In France, the residential retrofit market has the most important size - 80% of the houses that will be used in 2050 in France already exist - and represents the main source of energy consumption in buildings. Then, the energy consumption reduction in existing buildings, by using renewables for heating and cooling, has become a major stake in France.

Despite this favorable context and a fast growing success in new houses (18500 units sold in 2006, AFPAC 2007), GSHP are absent of the french residential retrofit market.

The main identified barriers to the development of GSHP in french existing houses are the ground collectors installation costs and the needed area in gardens. The development of the compact collectors by IVT (Wärnelöf 2005) was made to overcome these barriers, and in particular to reduce the installation cost.

This paper describes field tests and simulation results made in France, in french retrofit market conditions and analyses the possible development of GSHP on the french retrofit market thanks to these compact collectors.

2 DESCRIPTION OF THE COMPACTS COLLECTORS SYSTEM

System elements

Compact collectors

The compact collector is a modular ground heat exchanger built in PEM, Poly Ethylene (figure 1 left). The collector consists in a number of 40 mm pipes connected with U-bends at the top and at the bottom. Each module has the dimensions 1500 x 2000 mm (width x height). Due to the large pipe diameter, up to 10 modules can be connected in series. Modules are easily connected with weld connections or screw ones. Each top connection has a de-airing device to speed up the filling process.

Heat recovery unit

The compact collectors are commercialized in Sweden with a heat recovery unit (VBX). The VBX is an exhaust air/brine exchanger, consisting in a fan and a brine coil for heat recovery. The principle of the VBX (figure 1, right) is to be used as :

- an auxiliary system when the heat pump is on ;
- a ground reloading system when the heat pump is off.

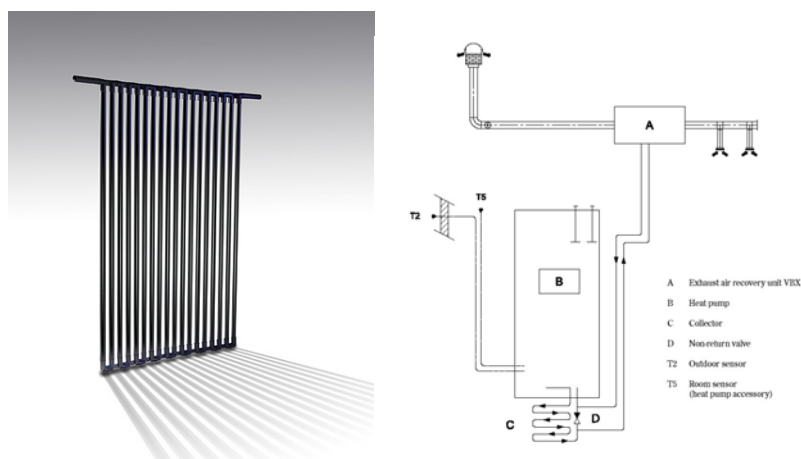


Figure 1 : compact collector system with VBX

Compact collectors sizing and installation methods

Installation methods

Historically, the compact collectors could be installed in two ways: vertically or horizontally (figure 2).

- For the vertical installation (preferred and most compact), the modules are put in 3 meters depth trenches (0.5 to 1 m width). The spacing between to trenches has to be at least 3 meters.
- For the horizontal installation (wet or sliding ground conditions), the collectors are put at 1.5 to 2 m depth with the connections slightly higher than the bottom of the module.

In Sweden, even installations in V-trenches have been evaluated (figure 2). The V-trench is 2.5 or 3 meters depth, 4 meters width at the surface and 1 meter width at the bottom. A serie of modules is put on each inclined surface of the trench.



Figure 2 : Vertical, horizontal and V-trenches installations

Sizing method

A sizing software, specific to these compact collectors, has been created, based on a theoretical model developed by G. Hellström (Hellström, 2004).

To have a first estimation, a very simple sizing rule has been deduced from this software, consisting in multiplying the heating capacity of the heat pump by a numerical factor, depending on the installation configuration:

- with VBX (whatever the modules position is) :
nb of modules = heating capacity (kW) x 1,5
- without any auxiliary system and horizontal position :
nb of modules = heating capacity (kW) x 3

Compact collectors system and french retrofit market constraints

These compact collectors, possibly installed in narrow trenches, can be very interesting for the french residential retrofit market ; the french old houses having very small available garden areas. The horizontal installation, even if it's easier, implies a needed area larger than most of french common gardens.

However, despite a french law of 1982 (ventilation 1982) that imposes a global, not necessarily mechanical, ventilation system, the mechanical ventilation systems are not so frequent in french old houses, less than 20% of the houses built in the 80s are equipped. Then, in order to evaluate the possible advantages of compact collectors system on the french market, they have to be tested in two ways : with and without the exhaust air unit (VBX), to reproduce the most frequent configurations.

3 FIRST FIELD TEST IN AN EXISTING HOUSE

The first field test was undertaken by Geminox in Brittany (France) with the following climatic conditions :

- standard base outside temperature of -4°C
- 2438 heating degree days
- heating period of 6 months from 2006, october 15th to 2007, april the 15th

The system was installed in an existing house. The data were registered during 15 days in february, 2007 (the average outside temperature was 10°C, which is particularly high). This dwelling is a 130 m² house and it was built in 1994. Therefore it was equipped with a standard exhaust air unit (~150 m³/h). Former heating system was a standard propane boiler on which the owner paid a rental of 150 €/month (included VAT).

Sizing and installation process

Sizing of the installation

This house has a peak load of 6. Then, the Geminox ECOLANE SE6C heat pump (6 kW heating capacity) was installed. The system was also equipped with the VBX unit in replacement of the existing air exhaust unit.

16 compact collectors were installed in a 100 m² garden¹ in 4 parallel narrow trenches (figure 3, left), even if, referring to the simplified rule for calculation of compact collectors number, 9 compact collectors should have been enough. However, the 16 collectors were chosen to be independent of the function of the VBX unit and to be able to evaluate the performance with and without reloading.

Hydraulic valves could shut off one trench or more to evaluate the oversizing of compact collectors.

Two kinds of emitters are connected to the HP: a floor heating circuit (heating distribution temperature of 35°C, 1st floor) and some radiators (heating distribution temperature of 55°C, 2nd floor). Radiators were possible, due to the high temperature heat pump used (maximum distribution temperature of 65°C). Therefore, radiator circuit steers temperature levels, and a mixing valve provide a suitable temperature to the under floor heating circuit.

Installation process

Inside installation

To prevent short cycle for the compressor, a 100 liters buffer tank has been placed in parallel between the heat pump and the heating circuits.

Both heating and domestic water demands are supplied by the heat pump. Beside, a storage tank (290 liters) connected to the heat pump provides hot domestic water.

The existing chimney was used as a direct way from the first floor (heat pump location) to the storehouse under the roof (VBX location, figure 3, right)).



Figure 3 : Field test installation in an existing house

Ground collectors installation

Some difficulties have been met during the digging: a too high depth trench makes too many landslips. The filling up substance used was river sand mixed with existing ground in order to get a maximum contact area between ground and compact collectors and avoid any air bubbles (30% sand and 70% existing ground) .

¹ 220 m² is required for instance with horizontal ground loops according to the manufacturer for a 6kW heat pump.

Some results

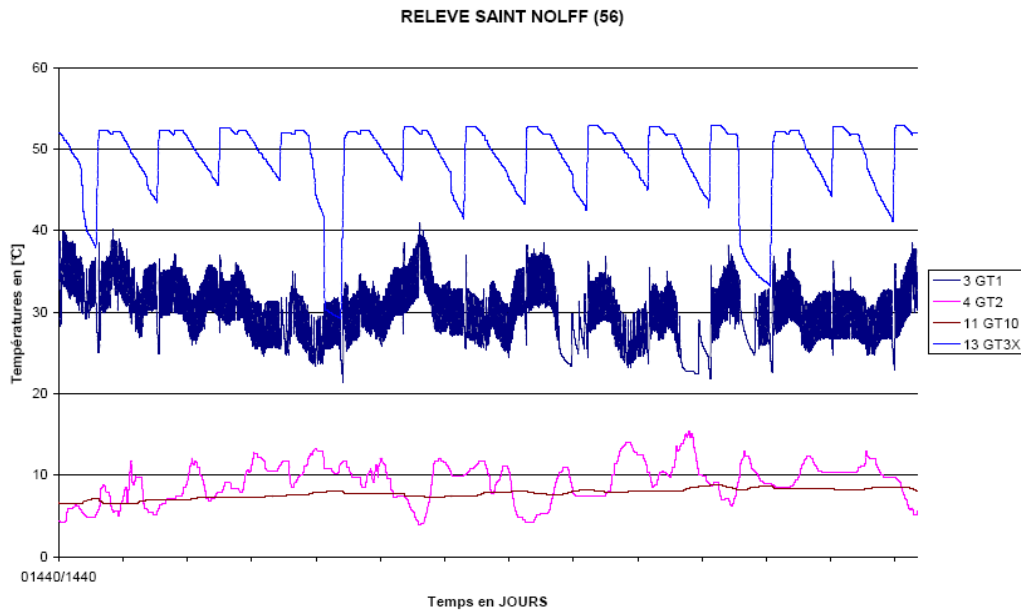


Figure 4 : Data report of 15 days results

Brown : brine water inlet temperature
Pink : outdoor temperature
Blue : domestic water temperature
Dark blue : return temperature from emitters.

Brine temperature is quite high with an increasing tendency, following the outside temperature evolution (figure 4). Despite the short time report for this field test (from the 07/02/07 to the 21/02/07) and the quite high values of outside temperature during this period which influence the brine temperature results, it's probable that the ground collectors are oversized. It seems that 9 modules, number corresponding to the first estimation base on the simplified rule, constitute the good sizing for this installation.

From a entire year period (November 2006 to November 2007), seen from the end customer, the whole electrical invoice is:

- 200 € as fix price of electricity per year.
- 320 € as variable cost covered by all electrical appliances in the dwelling (excepted HP)
- 316 € as electrical cost covered by the heat pump.

4 SECOND FIELD TEST ON THE EDF TEST PLATFORM

The Natural Climate Platform of EDF R&D

The second field test of compact collectors, in France, was realized on the "Natural Climate platform" of EDF R&D (figure 5). This platform consists in testing real GSHP, with a 3000 m² area dedicated to the installation of ground collectors and a room dedicated to the installation of several heat pumps, and in simulating the thermal response of a house of about 150 m² with various insulating levels.

The thermal response of the house is simulated using a water tank of 500 liters for the inertia and a controlled evacuation loop connected to an air cooler to evacuate the heat produced by the heat pumps.

The platform is located in the region of Paris. Therefore, the tests are conducted with the following climatic conditions :

- base outside temperature of -7°C
- 2674 heating degree days
- heating period of 6,5 months from mid october to the end of april

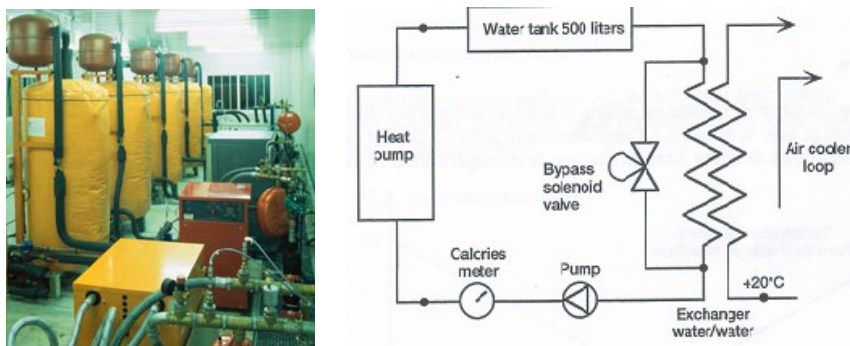


Figure 5 : Principle of the house thermal behaviour simulation on the EDF platform

Sizing and installation process

System sizing

As the platform simulates the thermal behavior of a 150 m^2 existing house, with an average level of insulation corresponding to a house built in the 80s, the heat pump Ecolane SE9 (9 kW at B0/W35²) of Geminox was chosen.

As seen above, a very simple sizing rule of the ground collectors has been determined. It permits to obtain the necessary number of modules, depending on the heating power and the installation conditions. The configuration tested on the EDF platform - vertical trenches without the VBX unit - has never been tested and the factor multiplying the heat pump capacity to obtain the number of modules to be installed has to be estimated.

Two aspects were considered to determine this factor :

- as no auxiliary system is associated to the ground collectors, the factor is at least equal to 3 ;
- the natural ground reloading, by rain water infiltration and sun, is less efficient in case of narrow 3 meters depth trenches than in case of 1,5 meter depth horizontal installation. The factor has to be slightly higher than 3.

Then, a factor of 3,5 was chosen and 32 modules were installed, distributed in 4 trenches.

We chose to simulate the behaviour of a heating installation equipped with radiators designed with a heating distribution temperature of 60°C at the standard base outside temperature (-7°C).

Instrumentation

The goal of this one year field test was to evaluate the compact collectors performances. It induced to check :

- the ground collectors sizing
- their ability to supply the required thermal energy
- the impact of ground collectors on the surrounding ground

² Heating power supplied for a brine temperature at the evaporator inlet of 0°C and a water temperature at the condenser outlet of 35°C .

This goal implied the analysis of various parameters concerning the GSHP functioning as well as the ground parameters. The recorded (each minute) parameters were the following:

- thermal energy supplied to the evacuation loop
- water flow and temperatures (inlet/outlet) at the evacuation exchanger
- absorbed electrical energy (compressor and circulating pumps)
- brine temperatures (inlet/outlet) at the evaporator
- outside air temperature and humidity
- reference ground temperatures at 60, 90 et 120 cm depth
- ground temperatures at 15-20 cm of the first and last modules of two trenches, at 1, 2 and 3 meters depth
- ground temperature at 1 meter depth between the two central trenches

Installation process

The installation process was long (several weeks) and complicated, for two main reasons :

- the drilling of very thin trenches, of 3 meters depth (figure 6, left), was very hard because of geological conditions. Ground near the test platform is mainly composed of sand with spits of limestone. The ground vibrations when the mechanical shovel tried to crush the limestone caused landslides.
- the trenches filling up was very tedious because of the necessity to filter the soil before re-introducing it in the trenches (figure 6, right).



Figure 6 : Trenches drilling and filling up

This installation process is then delicate and tedious to implement when more than 2 or 3 trenches are necessary to cover the heating needs ; seeming to be the case for old french individual houses.

However, the trenches configuration is very modular compared to the usual horizontal ground collectors one, each trench being independent of the others. That can be an interesting advantage if the installation is limited to 2 or 3 trenches, that can be "disseminated" in the garden.

Seasonal and nominal performances

The 2006/2007 winter was particularly nice in France : the seasonal average outside air temperature was 9°C, instead of less than 6°C usually. The installation, reproducing the heating system of a 150 m² individual house, had then to supply about 15000 kWh instead of about 20 000 kWh. Despite these favourable climatic conditions, the seasonal performances are interesting and significant enough ; but the behaviour of the system at nominal (sizing) conditions was more difficult to evaluate.

Supplied power and distributed water temperature

The tested heat pump was designed to supply 9 kW at B0/W35 and 8,5 kW at B0/W50, with a maximum distributed water temperature of 65°C.

As precised above, the weather during the winter was too nice to fully evaluate the system at nominal conditions (high distributed water temperatures); but, we could verify that the supplied power corresponded to the expected values (9 kW at approximately B0/W35, cf figure 7). The distributed water temperature was 55°C for an outside air temperature of -1°C (cf figure 8), and, very occasionally 60°C at - 5°C.

Then, the performances of the installation, for this season, were in accordance with the expected ones, but the system could not be tested exactly on the nominal performances because of the mildness of the climate.

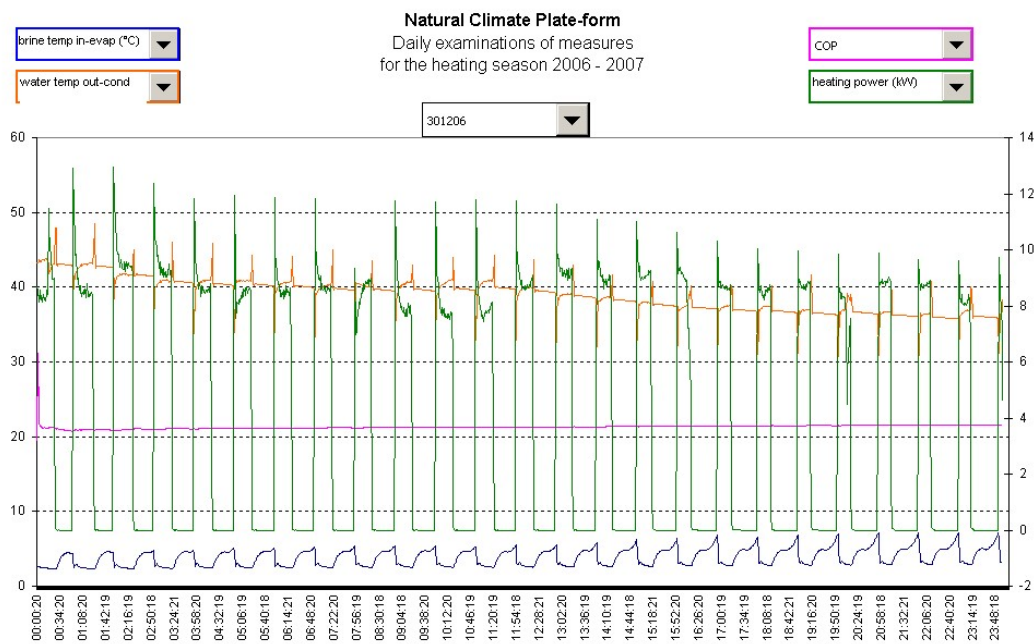


Figure 7 : Supplied power at ~B0/W35

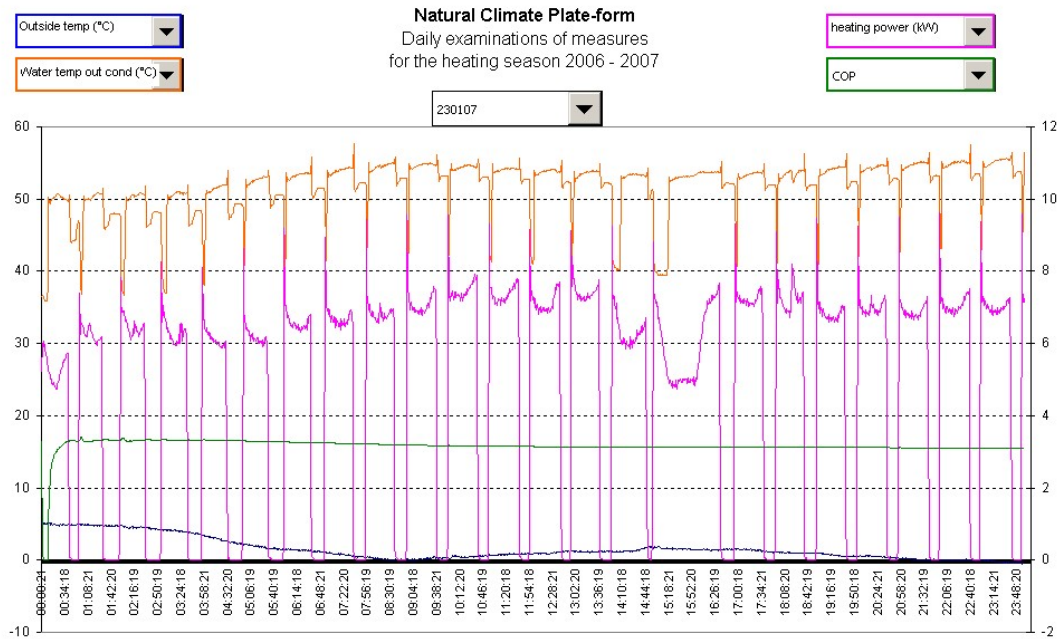


Figure 8 : Distributed water temperature

Coefficients of Performance and seasonal performances

Global aspects

The values of the coefficient of performance are spread out over a limited interval, thanks to a high and stable level of brine temperature at the evaporator, probably due to almost stable ground temperature at 3 meters depth. Moreover, we note that, after a period of high heat extraction during which the ground temperature decreases all the same, the ground temperature recover its initial level in few days (figure 9).

We can also mention that the brine temperature difference in the ground collectors is very low, between 2 and 2,5°C in most cases.

COP and SPF

The minimum COP is 2,8 for an outside air temperature of -6°C (B0/W60) and the maximum is 4,7 for an air temperature of 14°C (B12/W35). The figures 7 and 8 show values of COP of 3,8 for 8°C (B0/W35) and 3,2 at 0°C (B0/W55).

These values lead to a seasonal performance factor of 3,85.

The figure 9 shows the evolution of daily COP and ground temperature near the ground collectors inlet and between the two central trenches (about 1 meter far from the brine return pipe), during one month of test.

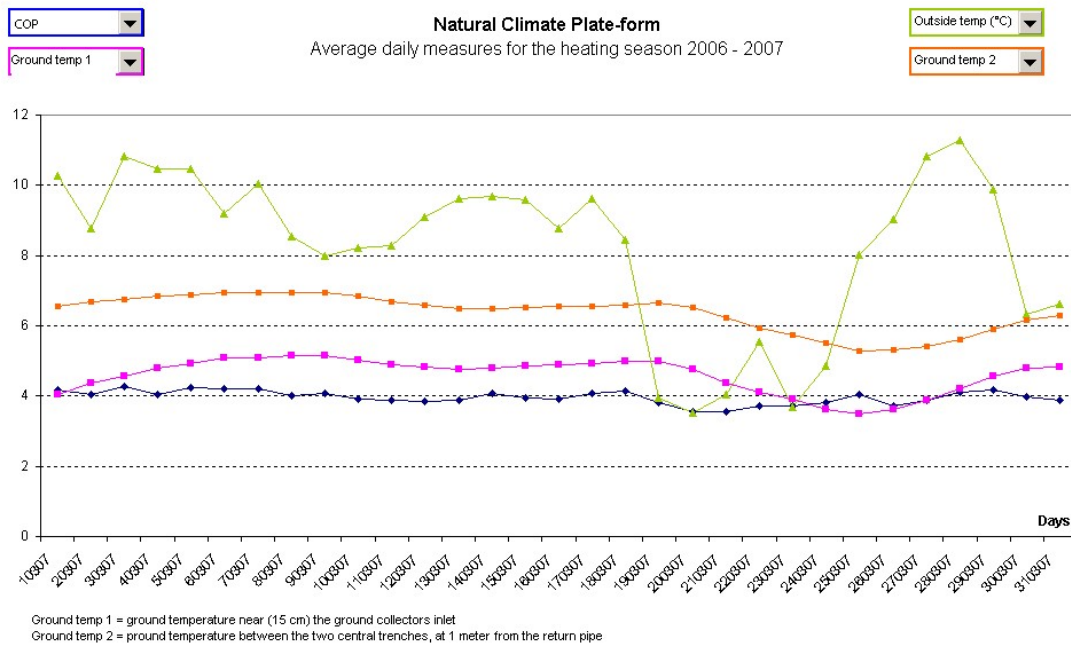


Figure 9 : daily COP and ground temperature during a month

The stable conditions at the evaporator, the homogeneity of the COP values and the high level of SPF are more typical of vertical ground collectors installations than horizontal ones. It can be also typical of oversized installations.

For this installation, both aspects are valuable :

- the relative stable conditions at the evaporator and the rapidity with which the ground recovers its initial conditions after a high extraction period (figure 9) signify that the position of the ground collectors - vertically in 3 meters depth trenches - seems to be a good compromise between the efficient natural ground reloading near the surface and the very stable ground conditions in depth.
- the low brine temperature difference between the inlet and the outlet of ground collectors shows that the system is certainly widely sized.

5 COMPARISON OF EDF TESTS AND SOFTWARE RESULTS

These tests, realized on the EDF platform, highlighted an uncertainty concerning the sizing of the compact collectors in the case of vertical installation without any ground reloading system. It appears, with these tests, that the first estimation of compact collectors sizing in this configuration, was overestimated. The problem is that, taking in account the particular climatic conditions during the tests, it's uneasy to determine exactly the oversizing.

Software principle

Then, we decided to make an EDF software evaluate in order to model the compact collectors. The first version of this software, developed by *Ecole Polytechnique de Montréal* in 2003, was dedicated to the borehole heat exchangers (BHE) sizing. This version was based on the thermal response of the ground near the BHE at three thermal impulses of different time orders (hour, month and year) (Bernier 2006). For a specific building (with specific hourly needs and functioning characteristics of the heat pump), the necessary length of BHE was determined to minimize the correction of temperature of the ground over a chosen period of use of the BHE (generally 10 to 20 years).

The second version of this software, also developed by *Ecole Polytechnique de Montréal*, has the same principle. It is also based on the thermal response of the ground at the same thermal impulses.

The difference is that the software, instead of calculating a BHE length, determines the best configuration of compact collectors to minimize the correction of ground temperature, for a given installation.

The impact of compact collectors configurations on the ground is calculated thanks to g-functions (Eskilson1987).

This software will have a library of 21 g-functions corresponding to 21 different configurations of compact collectors with various numbers of trenches and various numbers of modules per trench. For the moment, the tested configuration - 4 trenches of 8 modules - is the only simulated configuration.

Evaluation of compact collectors sizing

The principle of our study was to use the software to determine the heating capacity that correspond to the tested compact collectors installation (4x8 modules), for several ground conditions.

More precisely, the software calculates, for each simulated house and heat pump capacity configuration, the corresponding energy needs. It deduces the average brine temperature in the ground collectors at maximum load conditions and the corrected ground temperature with the compact collectors configuration of 4 trenches of 8 modules.

The software calculations show that to obtain common brine temperature levels (-1/-5°C³ at the maximum heating capacity, average value = -2,75°C), 4 trenches of 8 modules have to be associated to a heat pump of almost 11 to 13 kW capacity instead of 9 kW, depending on the ground characteristics, as seen on table 1.

Table 1 : software results

Max. heating needs (HP capacity)	Ground (thermal conductivity)	Average brine temperature (°C)
9 kW	saturated clay	-0,75
10,9 kW	saturated clay	-2,90
10,7 kW	saturated clay	-2,62
9 kW	Sand	1,12
10,9 kW	Sand	-0,66
12,1 kW	Sand	-1,84
12,5 kW	Sand	-2,45
9 kW	humid shale	- 1,73
12 kW	humid shale	-3,03
11,5 kW	humid shale	-2,77

This software calculation confirms the tests results : with 4 x 8 modules of compact collectors for 9 kW of maximum heating capacity, this installation was oversized, in particular on the test platform where the ground is mainly composed of sand.

The coefficient of 3,5 to calculate the necessary number of modules from the heat capacity of the heat pump in the case of installations with compact collectors installed vertically and without any ground reloading system is too high. A coefficient of 3, equal to the horizontal installation coefficient, seems to be more adapted. Compared to the horizontal configuration, in the case of a vertical installation in 3 meters depth trenches, the natural ground reloading is less favorable but the average ground temperature is higher and more stable. It seems that each of both aspects compensates the other.

³ The average temperature corresponding to a correct sizing is -2,75°C (-1/-5°C inlet/outlet ground collectors)

6 CONCLUSION

This study shows that ground compact collectors installed in relatively deep trenches can be of great interest, in particular in term of seasonal performances.

Even if, the 2006/2007 winter was particularly sweet, we can say that seasonal performances of such a ground source installation are indeed close to the borehole heat exchangers ones, thanks to an almost stable and high level of ground temperature at three meters depth.

In term of collectors sizing, this study, experimental as well as theoretical, shows that the installation in deep trenches is not penalizing, compared to horizontal installation. This is true with or without ground reloading and auxiliary system.

But, taking in account the great difficulties to drill narrow and deep trenches, the compact collectors sizing remains a problem for the residential retrofit market. The problem is particularly important on markets such as the french one, where the compact collectors can not be easily associated with an exhaust air auxiliary system (which permit to reduce the ground collectors sizing).

To introduce compact collectors on such retrofit markets, an other auxiliary system, easy to connect to the compact collectors, has to be developed.

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