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GROUNDHIT – advancement in ground source heat pumps through EU support

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ABSTRACT

Since summer 2004 the European Commission supports a project for R&D on advanced ground source heat pumps (GSHP). This project is coordinated by CRES (Greece), and connects partners from Austria, France, Germany, Poland, Portugal, and Romania. Beside the development of improved components an important goal is the transfer of experiences from the "classical" GSHP-countries into other regions, in particular East and South Europe and the Mediterranean.

The first project phase aimed at the development of the following components:

- Borehole Heat Exchanger (BHE) with good heat transfer efficiency and simple installation, in particular for regions lacking experience in drilling and installation of BHE.
- Heat pumps with high COP within the usual temperature limits for heat pump systems and BHE.
- Heat pumps with good COP also at elevated heating supply temperatures (retrofit in older heating systems).
- Heat pumps with high COP at elevated evaporation temperatures, e.g. from warm groundwater, thermal springs, etc.

Within the second project phase that started end of 2006 the components will be tested and demonstrated in some pilot sites in Greece, Austria, and Portugal.

The interim results achieved in phase 1 have been presented at an international workshop organised by GtV and EGEC in Brussels in May 2006. The presentations of the workshop are for download at http://www.groundhit.eu .

BOREHOLE HEAT EXCHANGER

The key element on the ground side of the GSHP is the borehole heat exchanger (BHE). The design targets of good heat transfer and simple installation lead to the adoption of a coaxial design. The coaxial BHE was already used in the early times of GSHP (fig. 1), and in the beginning of BHE application in Germany around 1980, the coaxial design was prevalent. The review of patent applications that was done within the project revealed several examples from Germany alone (fig. 2). In Germany, originally the coaxial BHE was the typical design (Sanner, 1987), while the double-U-tube came from Switzerland, about the same time (Rohner, 1991), and the single-U-tube from Sweden (however, also coaxial tubes have been used early in Sweden; see Mogensen, 1985)

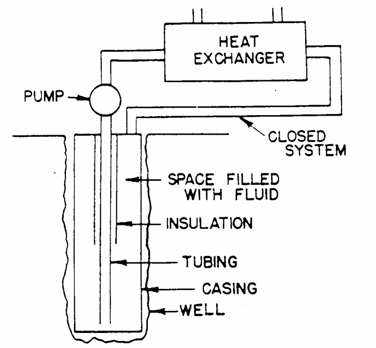

Figure 1: First drawing of a coaxial BHE, from Kemler (1947)

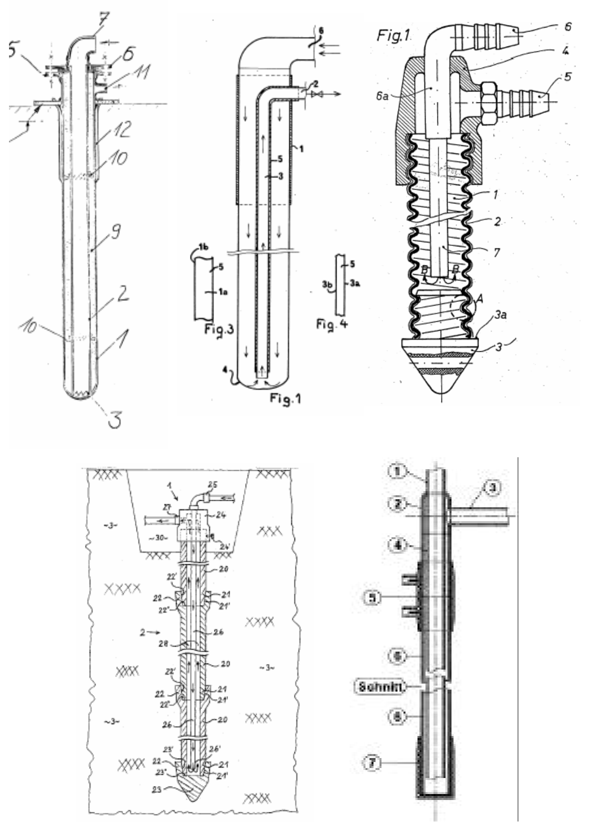

Figure 2: Examples of drawings of coaxial BHE from German Patent applications, upper row from left: Brocks & Richter (1980), Hinterding (1981), Hund (1983); lower row from left: Waterkotte (2003), Rosinski (2006)

The double-U-tube-BHE became standard in Central Europe around 1990 because it can be manufactured from cheap, standard plastic pipes simply by welding a U-turn-footpart to them. For the coaxial version, special material and more complicated manufacturing was required, resulting in much higher cost. This cost difference outweighed any other advantages the coaxial design might have. With the further development of materials and welding technology, the design of coaxial BHE became interesting again in the new millenium. As fig. 2 shows, a renewed interest can be seen also in the patent applications in Germany.

The GROUNDHIT BHE (fig. 3) is of a coaxial design (concentric, tube-in-tube) using standard plastic tubes and fittings, so no taylor-made components are required. The material PE-HD was chosen because of the following characteristics:

- outstanding toughness and breaking elongation
- good mechanical characteristics and chemical stability
- good mechanical characteristics and outstanding viscosity even at low temperatures
- good long-term behaviour
- low hydraulic resistance
- good cost-to-performance ratio
- existing and proven technology for connections

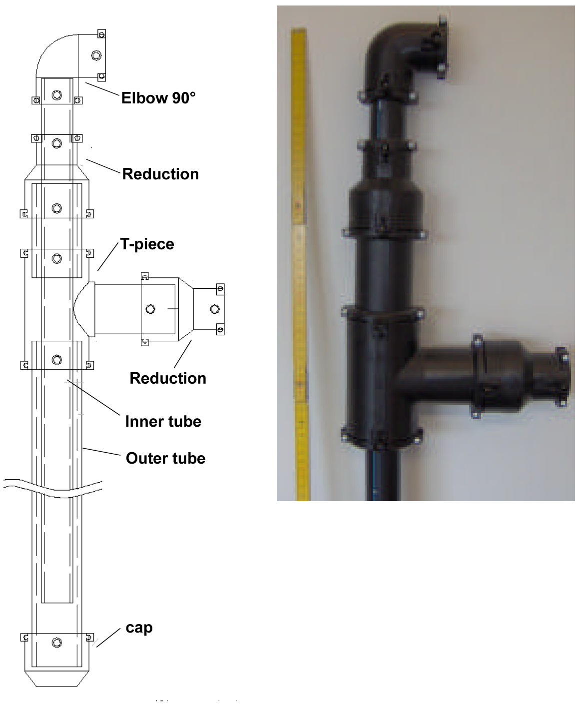

Figure 3: Drawing and photo of simple coaxial BHE as used in the GROUNDHIT project

The most important component of the BHE is the foot-piece. This part is subjected to the greatest strain during installation and operation. The advantage of the coaxial tube is that there is only one welding point, the foot cap. On standard double-U-tubes a minimum of four welding points has to be accounted for. As the aim was to develop a BHE that can easily be produced on site, if necessary, a low number of welding points is desirable. The diameter of the outer pipe has to be chosen big enough for a good heat transfer surface around the perimeter, and on the other hand small enough so that the pipe still can be delivered as one piece on a coil, and that the wall thickness needs not to be too high, in order to achieve the pressure range necessary.

To compare the price of different BHE systems, the most important parts have to be considered and calculated (table 1). The results can be summarised:

- The simple coaxial BHE with larger dimensions (75/40 mm and 75/50 mm) are too expensive and too difficult to install. The drilling diameter is larger and therefore inefficient.
- At smaller dimension (63/32mm), problems with the resistance of flow will be encountered.
- When comparing the typically used standard double-U-tube with the Groundhit simple coaxial at a dimension of 63/40mm, there is a cost reduction of nearly 300 € for a BHE of 100 m depth.

cost in Euro (€)	Drilling cost	Price per tube	Grouting material	Anti-freeze**	total
Double-U-tube 4 x 32	3750	677	238	432	5097
Single-U-tube 2 x 40	4000	426	309	334	5070
Simple coaxial 63/32	3750	439	241	362	4792
Simple coaxial 63/40	3750	478	241	340	4809
Simple coaxial 75/40	4100	617	263	504	5484
Simple coaxial 75/50	4100	680	263	456	5499

** 25 vol.-%

Table 1: Cost estimate for a complete BHE of 100 m depth, comparison of various designs

It should be noted that for the coaxial BHE only one PE-pipe of a bigger diameter must be installed instead of four pipes for the standard BHE. An important fact is to reduce the possible mistakes that can happen during installation. For the introduction into the borehole an aid should be used such as counterbalance weight or an uncoiling device. After installation of the outer pipe, the inner pipe can easily be put in afterwards. Then the T-piece and the reduction-piece can be welded onto the BHE top (fig. 3). Now the BHE is prepared to be connected with the heat pump system.

Because the borehole thermal resistance of a coaxial system can be quite favourable, efficiency of the BHE compared to double-U is improved. This results in a slight reduction in the necessary borehole length for a given heat pump (fig. 4).

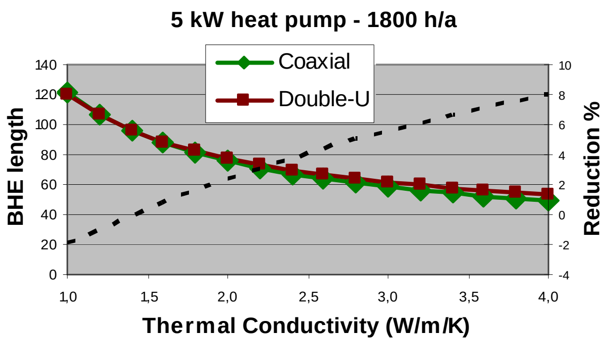

Figure 4: Necessary BHE length for a 5 kW heat pump, for different ground conditions; coaxial GROUNDHIT BHE compared to a standard double-U-tube BHE with 4 x 32 mm diameter

The coaxial BHE will be installed in the demonstration sites in Gleisdorf and Setubal (see below), and a check of the performance with thermal response test is planned.

ADVANCED HEAT PUMPS

The relevant heat pump development was carried out at CIAT in Culoz, France. The following prototypes have been built:

- High performance for standard GSHP applications (GROUNDHIT work package 2)
- High supply temperatures of 80 °C, mainly for retrofit applications (GROUNDHIT work package 3)
- High evaporating temperature up to 40 °C for use with thermal water (GROUNDHIT work package 4)

Work Package 2 prototype:

The key for high COP, beside good compressor efficiency, is low temperature loss in evaporator and condenser. For the GROUNDHIT heat pump, a pinch of less than 2 K in the evaporator and less than 1 K in the condenser could be achieved (fig. 5). Special brazed plate heat exchangers from the CIAT EXEL range have been used towards this goal, and a specific distribution device for the evaporator. A very efficient scroll-type compressor is used, without capacity control; the ground-coupling and hydronic heating allow for the simple on-off-control, which enables the compressor to run more under optimum efficiency conditions. The success reached with the work package 2 prototype (fig. 6) could be proven through lab tests (table 2).

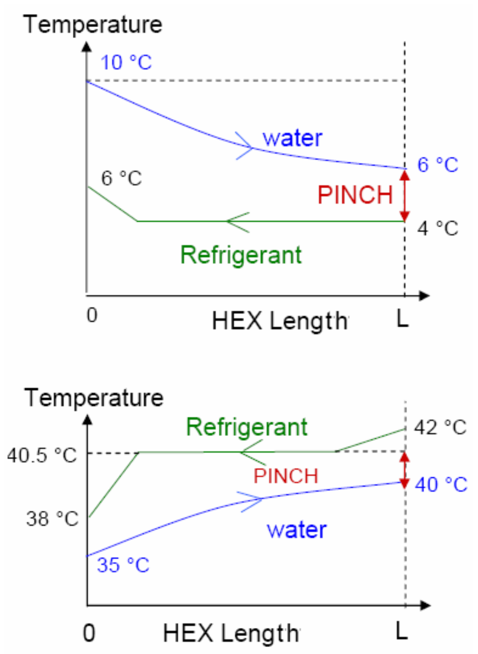

Figure 5: Temperature development in the heat pump for work package 2, over the length of the heat exchanger for evaporator (above) and condensor (below)

	[1] COP at 10/6 - 35/40°C	[2] COP at 10/* - 30/35 °C
GROUNDHIT WP2 pre-prototype	5.12	6.06
Typical value for GSHP on the market	4.5	5.4
Gain in %	14%	12%

[1] GROUNDHIT nominal conditions
[2] EUROVENT conditions

Table 2: COP of GROUNDHIT heat pump pre-prototype, compared with typical results for the best GSHP tested at Töss test centre, Switzerland

An increase of 12-15 % in the annual COP over the market average, as can be expected from the lab tests, means savings in the annual electric power bill of about 150 €, and can save up to 1.0 tons of CO_2-emissions a year, calculated for a heat pump unit with 15 kW heating capacity (exact conditions for calculation see in the appendix).

The prototypes for the high efficiency heat pump (final outer design as shown in fig. 6) will be equipped with:

- Reversing 4 way valve (for cooling operation in summertime);
- DHW system production with storage tank (300 l);
- CIAT micro-connect electronic regulation.

This prototype with heating/cooling mode is intended for test at the Setubal field test site (see below).

Figure 6: Test setup of components of the work package 2 prototype

Work Package 3 prototype:

While the heat pump for work package 2 is well advanced and close to the market, the high supply temperatures aimed at in work package 3 require more basic development work, starting with the investigation into suitable refrigerants. From the standard range, only R134a and R290 (propane, a natural refrigerant) have a high enough critical temperature to be considered (table 3). Another option would be a transcritical fluid, e.g. R744 (CO_2). In this case the heat delivery step of the heat pump would be completely in the steam field, with a gas cooler instead of a condensor. Test runs with several configurations, including CO_2, have been run at the CIAT labs.

Refrigerant	R134a	R290	R407C	R410A
Critical temperature (°C)	101.1	96.8	87.3	72.2

Table 3: Critical temperature of typical refrigerants

A goal is to reach a COP of about 3 with a heating supply temperature of 80 °C, and the standard ground side conditions for BHE systems. The prototype shall be tested on the Gleisdorf field test site.

Work Package 4 prototype:

In many places in Europe low-temperature thermal waters exist, at a temperature somewhere between 15 °C and 40 °C. This temperature is too low for direct heating, but on the other hand too high as a heat source for a standard groundwater heat pump. The heat pumps currently on the market allow evaporation temperatures of slightly above 10 °C (fig. 7). With adapted compressor technology, in the first step an increase of the possible evaporation temperature to ca. 20 °C is planned. The relevant prototype will be tested in the Thessaloniki field test site.

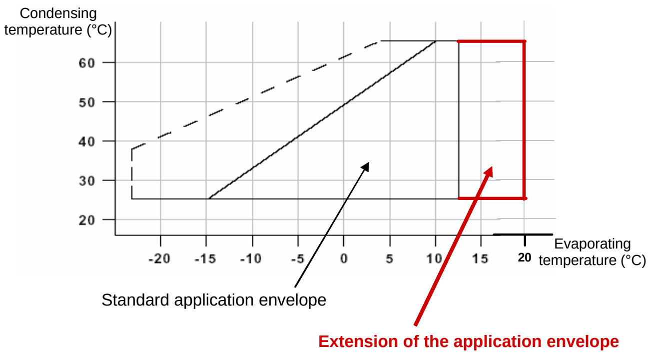

Figure 7: Envelope created by condensing and evaporating temperatures of typical heat pumps, and extension needed to adapt to thermal waters

FIELD TEST / DEMONSTRATION SITES

The demonstration sites (fig. 8) have been selected in order to best serve different purposes:

- In Setubal (Portugal), the high efficiency heat pump for standard conditions (from work package 2) will be tested and demonstrated. The climatic conditions call for a substantial cooling load; the heat and cold distribution follows standard practice. The critical part in the Setubal test site is on the ground side; ground source heat pumps yet are a novel application in Portugal, and experience with drilling and installation for BHE is non-existent. So this site offers optimum conditions for testing the setting-up of a GSHP system for heating and cooling in Southern Europe.
- The Gleisdorf site in Austria is located in a country with large experience in GSHP. The ground side should not cause any problems to the skilled Austrian drillers. The critical point here is in the heating supply side, where high temperatures for retrofit applications in existing buildings are required. With GSHP firmly established on the market for new buildings in Austria, the step into the much larger market of existing structures now can be demonstrated, and the huge potential for energy saving and emission reduction on that market in all of Central Europe might be opened.
- The site near Thessaloniki in Greece offers a low-temperature thermal water in a temperature range encountered often in the Mediterranean region. Thus the test of the heat pump with elevated evaporation temperature from work package 4 can be carried out here.

Demonstration site Setubal:

The Portuguese demonstration site is located on the campus of the EST, just outside the building of the mechanical engineering department. The heat pump will be installed in the ground floor lab; 5 BHE each 80 m deep will be placed under the lawn outside, in a zig-zag line in order to maximise BHE spacing on the given area (fig. 9). Two different types of BHE will be compared (double-U and coaxial). An additional borehole, completed as groundwater well, can serve for access to the underground.

In the underground on site a layer with low permeability is known at ca. 80-150 m depth (fig. 10). This layer protects the deeper aquifers from infiltration of poor quality groundwater near the surface. In order to keep that protection active, the BHE should not penetrate into this layer, and BHE depth thus is limited to ca. 80 m.

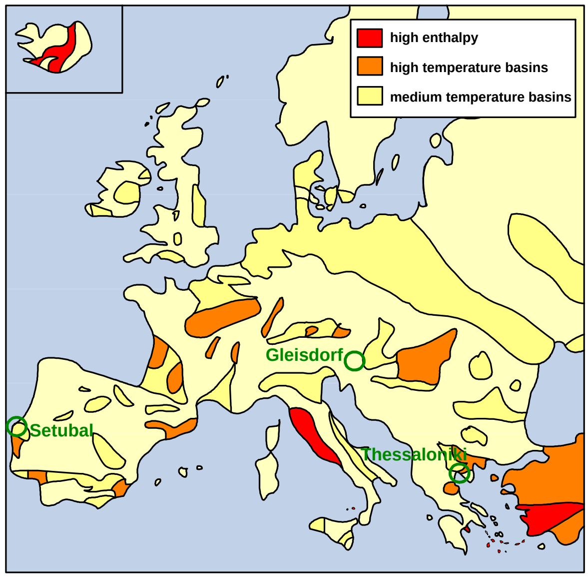

Figure 8: The three GROUNDHIT demonstration sites in the framework of the European geothermal structure

Figure 9: Location of BHE and groundwater well outside the EST mechanical engineering building

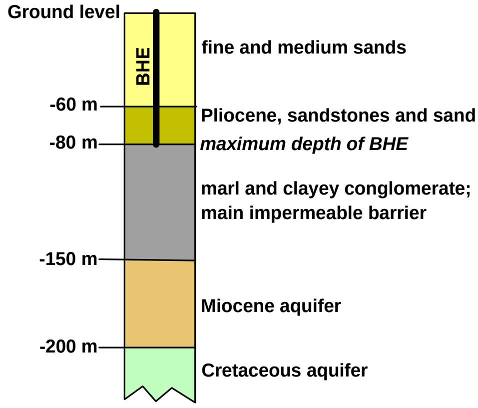

Figure 10: Geological underground situation at EST mechanical engineering building site

The connection to the heat pumps is designed in such a way that the two heat pumps can be individually connected to one or more of the BHE (fig. 11). This is a more complicated connection than found in commercial applications, but it allows for individual testing of each BHE or groups of BHE as desired.

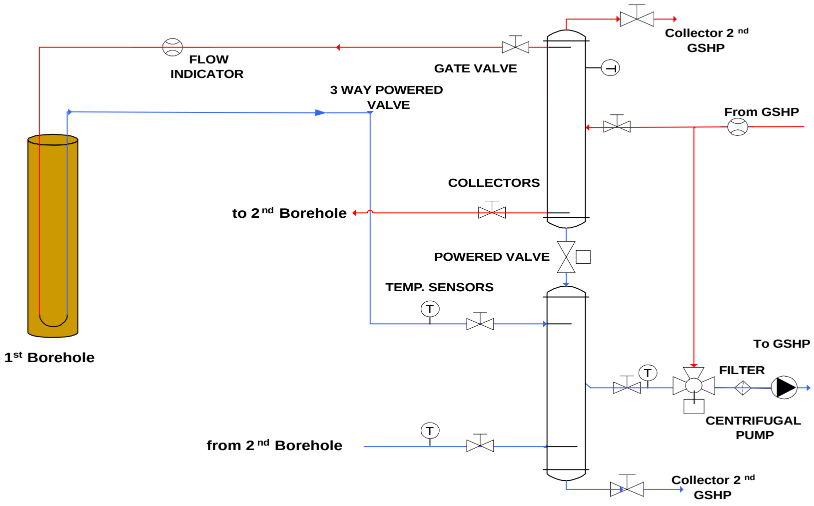

Figure 11: Installation schematic of BHE connection to heat pumps in EST mechanical engineering building

Demonstration site Gleisdorf:

The underground at the Gleisdorf test site consists of Tertiary sediments, mainly shales and sandstones with some gravel layers (fig. 12). Only one heat pump is planned, the prototype from work package 3 with high heating supply temperature of 80 °C; therefore 2 BHE of 125 m depth each are sufficient as heat source. The heat pump will be installed in the "Solarschau" (solar energy exhibition building) of the local utility Feistritzwerke (fig. 13).

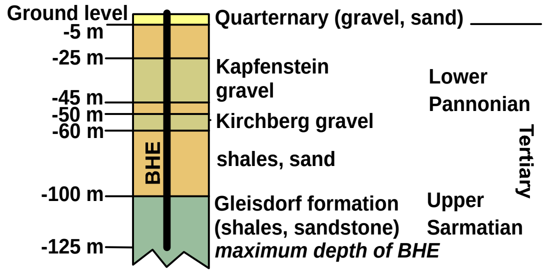

Figure 12: Geological underground situation at Solarschau site in Gleisdorf

Figure 13: Solarschau of Feistritzwerke, Gleisdorf

Demonstration site Thessaloniki:

This site is intended for the work package 4 heat pump prototype with elevated groundwater temperature. The location is in the village of Thermis to the southeast of Thessaloniki (near the airport), and the exact name is Neo Ryssio. 2 wells already exist at the site, one for production, and one for re-injection (doublet); well #1 (re-injection) is 660 m deep, well #2 (extraction) is 405 m deep.

The underground situation can be seen in figure 14. The production well can deliver at least 5 m^3/h of water at 27-28°C with pumping.

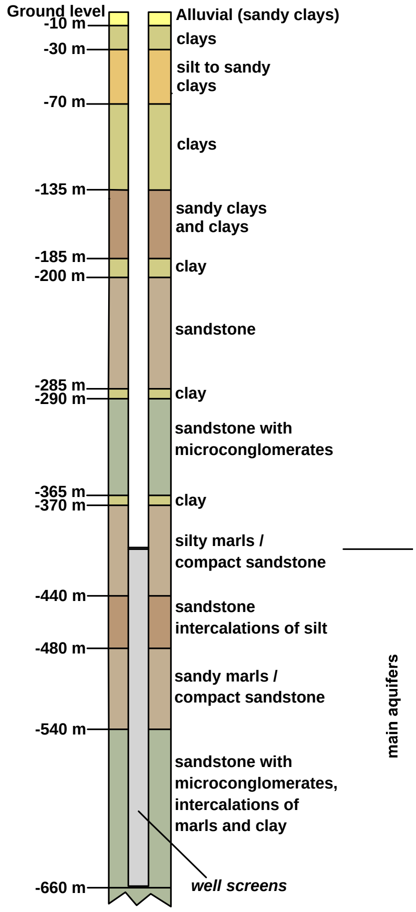

Figure 14: Geological underground situation at Neo Ryssio site in Thermis, Thessaloniki

The heat pump will be placed in the premises of "Keramopoiia Christodoulidis", a bricks/tiles manufacturer across the road. It will be used to heat the bathhouse and the small dwelling where the watchman and his family live, and to provide hot water for bathing; cooling is also needed during the summer period. Sleeve pipes exist already beneath road for connection of the wells to the heat pump.

Demonstration sites in general:

The design calculations for the BHE layout in the Setubal and Gleisdorf plants have been done using the software EED (Hellström et al., 1997). A typical annual temperature development is shown in figure 15.

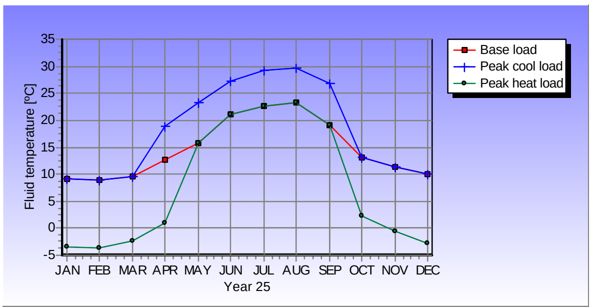

Figure 15: Temperature development in the 25th year of operation in EST Setubal BHE, calculated with EED

Two more test sites are under consideration in Austria:

- A possible second demonstration site for the high heating supply temperature heat pump (work package 3) is investigated in Linz, Upper Austria, at a demonstration centre of the regional electric utility; a BHE exists already in that project.
- An interesting application of the heat pump with high input water temperature (work package 4) is considered as a booster in the geothermal district heating network of Simbach/Braunau at the German/Austrian border.

CONCLUSIONS

The current projects status shows that a good efficiency of a ground source heat pump can be achieved with advanced components (heat pump), but simplified installation techniques for the ground side coaxial borehole heat exchanger). The advanced heat pumps developed for the standard application are close to the market and will form a part of CIAT´s Aurea line (fig. 16). Also the extension of the ground source heat pump technology towards heat supply temperatures hitherto not possible, and towards application of heat sources with elevated temperature, seems very promising.

Figure 16: Internal layout and outer appearance of the heat pumps under development, matching the looks of the Aurea 2 line by CIAT

The installation and operation of the ground source heat pump systems at the different demonstration sites will allow to study the practical application in more detail, and to gain experience with layout and construction of the GROUNDHIT heat pump system.

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APPENDIX

The boundary conditions for the calculation of the advantages of the GROUNDHIT work package 2 heat pump are:

-	Heat pump heating output:	15 kW
-	load factor of the heat pump	30 %
-	for the GROUNDHIT prototype	SPF=5,12
-	for the competitor machine	SPF=4,5
-	electricity costs	14 cents per kWh_e
-	ratio of primary energy over electricity for the CO_2 emissions	3,0
-	1 kWh_t =	344 gr CO_2