GROUND COUPLED HEAT PUMPS OF HIGH TECHNOLOGY

- Results from the European research project GROUNDHIT

Technology sheet

Innovative Technology
- 3 Water source heat pumps: 1 of improved COP, 1 of delivering 80^{O} water for high temperature heating, 1 of extraordinary COP for warm ground water

General information:

- Name of technology: GROUND COUPLED HEAT PUMPS OF HIGH TECHNOLOGY
- Technology developer: C.R.E.S.
- Location (address, Country of technology developer): 19th km Marathonos Ave, 19009, Pikermi Attiki Greece
- Date of issue (year): 1 June 2004

Aims and Objectives:

The GROUNDHIT project **aims** at improving cost-effectiveness and competitiveness, and facilitating market penetration of geothermal heat pumps by:

- Optimising in terms of heat transfer with the earth, standardizing and developing an industrial borehole heat exchanger (BHE) prototype, which when placed within the earth, it will form a coaxial vertical borehole heat exchanger.
- Optimising ground source heat pumps (electrical water source heat pumps intended to be used together with a borehole heat exchanger) in terms of COP: theoretical design, laboratory experimentation and industrial prototype development of COP>5,5.
- Developing electrical ground source heat pumps able to deliver 80 ºC hot water in contrast to market available units which deliver 55-60 ºC maximum: theoretical design, laboratory experimentation and industrial prototype development.
- Optimising electrical water source heat pumps intended to utilize warm groundwater 20-40ºC in terms of COP: theoretical design, laboratory experimentation and industrial prototype development of COP>7.
- Demonstrating above technologies at 3 sites: (a) ground source heat pump of high efficiency prototypes coupled with borehole heat exchanger prototypes in Portugal, (b) ground source heat pump delivering 80 ºC heating water coupled with borehole heat exchangers in Austria and (c) water source heat pump of very high efficiency coupled with a warm groundwater well in Greece.
- Support market introduction and dissemination of the developed technology, by a series of studies, organising two workshops, participating in promotional events and technical and scientific publications.

In order to effectively manage the project, **objectives** were defined in terms of (a) researching, (b) demonstrating and (c) disseminating ground source heat pumps of advanced technology for heating, cooling and domestic hot water, as follows:

A. Research objectives

1. Designing borehole heat exchanger parts that can be mass-produced and can easily be assembled on site to a borehole heat exchanger.
2. Designing a geothermal heat pump of improved efficiency (COP=5,5) suitable for operation together with a borehole heat exchanger.
3. Designing of a water source heat pump able to deliver 80ºC suitable for operation together with a borehole heat exchanger.
4. Designing of a water source heat pump of exceptionally high efficiency (COP=7), able to utilise geothermal water up to 40ºC.

B. Demonstration objectives

5. Evaluation of research results for improved heat pumps in terms of COP and temperature range; manufacturing successful prototypes for demonstration.
6. Demonstrating, testing and validating a ground coupled heat pump system comprising:
   - the developed geothermal heat pump of COP>5,5 coupled with
   - the developed borehole heat exchanger, and

European Project "Eco-Building International Club for advanced European sustainable energy technology dissemination in Europe and China"
Project partners:
ENEA (IT), ISNOVA (IT), FINCO (IT), ADEME (FR), AIMCC (FR), DTI (DK), DI (DK), CRES (GR), EBHE(GR), GPREC (GR), SEC(B), ZERI (CN), CBEEA (CN)
SIXTH FRAMEWORK PROGRAMME

- heating and cooling system

o The demonstration site will be in Setubal (Portugal)

7. Demonstrating, testing and validating a ground coupled heat pump system comprising:
   - the developed heat pump able to deliver 80ºC coupled with
   - borehole heat exchanger, and
   - heating and cooling system

   o The demonstration site will be in Gleisdorf near Graz (Austria)

8. Demonstrating, testing and validating a ground coupled heat pump system comprising:
   - the developed water source heat pump of COP>7 coupled with
   - a geothermal well yielding warm water 25-40ºC
   - heating and cooling system

   o The demonstration site will be in Neo Ryssio near Thessaloniki (Greece).

C. Dissemination objectives

9. Making the necessary intellectual property protection arrangements for the knowledge and new technology produced.
10. Disseminating the developed technology to a global target group.
11. Facilitating the market penetration of the developed technology.

A Short Description of the Technology:

Innovative technology developed in 4 points.

1) Borehole Heat Exchanger (BHE)

2) Ground Source Heat Pump of high Efficiency

3) Ground Source Heat Pump of high Temperature

4) Ground Source Heat Pump for warm Groundwater

Borehole Heat Exchanger (BHE)

At first stage the state of the art of borehole heat exchangers technology has been identified in terms of geometry, piping materials, footpart, fluid properties, installation, energy output, applications, patents granted, design methodology and related software, documentation. Tasks performed included technology assessment, materials evaluation, computer simulation, geometry formulation, and first steps towards drafting prototype engineering design. In detail, the following tasks were undertaken aiming in improving BHE technology beyond the state of the art, towards the project objectives. BHE technology development included market research on new technologies, review of patents, computer simulations using the EED software package, preparation of design guidelines, and development of an advanced BHE, comprising pre-fabricated parts, which can be assembled on site. As there was little room for further improving the double-U tube technology, the coaxial BHE type was selected for this purpose. The advanced coaxial BHE pre-prototypes that were developed are characterized by high thermal efficiency (i.e. low borehole thermal resistance), low cost for material and construction, high longevity, durability, and easy installation.

The project aims at promoting and widespread disseminating EU innovative Research and Technology Development and Demonstration results, as well as eco-sustainability criteria in building sector, which include:
- energy efficient building materials, components and systems not yet introduced into the building market or in their first market phase;
- innovative applications of heating/cooling and power supply technologies, combined with the use of renewable energy sources, in building sector;
- best EU demonstration eco-building projects.

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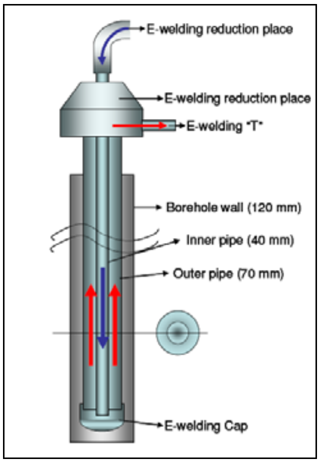

Borehole Heat Exchanger Coaxial Type; ***left:*** on site photo of its top as installed at the Setubal campus; ***right:*** schematic cross section and water flow.

Ground Source Heat Pump of high Efficiency

Research on heat pumps started intensively from the very beginning of the project. Firstly the exact boundary conditions for the COP measurements were defined in order to evaluate the prototypes in terms of achieving the project objectives. These are referred as Groundhit nominal conditions and correspond to 10ºC source water and heat supply at 40ºC. The heat pump prototype capacity was set to 15 kW(th). In these conditions, which correspond to an intermediate point between floor heating and fan-coils heating, the value of COP=5,0 corresponds to technology breakthrough. At that time, there was no compressor available on the market that could yield this energy efficiency. Considering that the compressor is the "heart" of the heat pump and the single component which consumes energy of high value, CIAT initiated meetings with European compressor manufacturers in order to investigate products under development and stimulate the development of the new generation of high efficiency compressors.
Compressor assessment technology included compressor efficiency, application envelope, capacity modulation, market survey, laboratory testing, selecting and testing the best compressors. Heat exchangers technology development included market survey, technology assessment, seeking ways to improve the state of the art, as well as optimizing refrigerant distribution. Expansion devices included commercially available thermostatic and electronic expansion valves. The test rig included compensation device, instrumentation and data acquisition hardware and software.
A series of ground source heat pump pre-prototypes have been assembled and tested including on/off control, digital and inverter modulated units of new technology. As the modulated pre-prototypes did not yield the COP required to achieve the technology breakthrough point defined in the contract, the best on/off pre-prototype was selected for the prototype development phase, which yielded COP=5,15 at nominal Groundhit conditions.
Next activities included final testing of the pre-prototype, as well as prototype development and manufacturing two units, which have been sent to the Setubal demonstration site. The prototypes are 20% more efficient than CIAT standard range, with COP=5,2 at Groundhit nominal conditions (10/6//35/40°C), and COP=6,2 at Eurovent conditions for floor heating (10/6//30/35°C).

Eco-Building Club: an innovative RTD&D results' promotion approach

Different from common market promotion approaches, where market operators are only simple message receivers, the project proposes an innovative approach: Eco-Building Club is a virtual round table, around which building market operators will be main actors for market penetration of research and demonstration results, through the following actions:

- determining what are more appropriated innovative RTD&D results for local market transferring;
- demonstrating the feasibilities of the research and demonstration results on real cases.

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Testing conditions Eurovent CHF	Evaporator water temperature		Condenser water temperature		Heating capacity (kW)	Input Power without pumps (kW)	COP
	Inlet (°C)	Outlet (°C)	Inlet (°C)	Outlet (°C)			
AUREA 2 50 HT	10	*	30	35	16.1	3.12	5.16
High Efficiency Prototype	10	6	30	35	17 (+5.6%)	2.76	6.2 (+20%)

Table 1: Groundhit high efficiency prototype energy performance measurements compared with other market available units of high efficiency at Eurovent floor heating conditions.

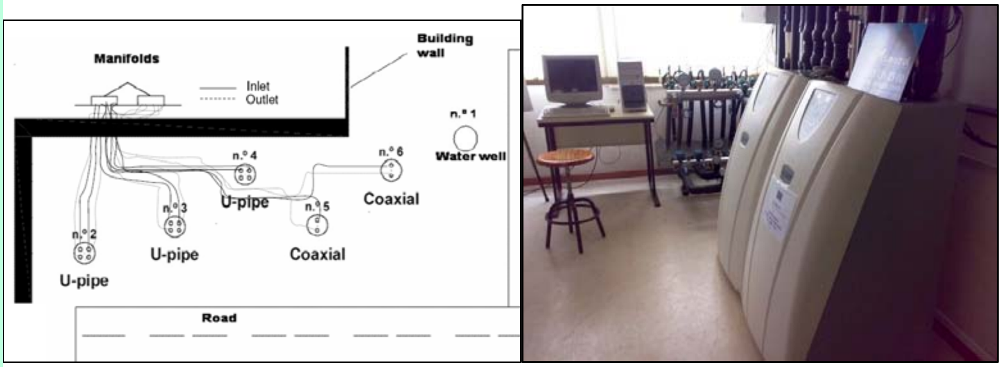

Fig 3: ***Left:*** BHE field and their connection to the manifold and the heat pumps. ***Right:*** heat pump prototypes with the manifold and the data acquisition PC shown at the back.

Fig 4: View of heating/cooling distribution piping and fan-coils

All market operators are invited to join Eco-Building Club!

Apart from awareness of most recent EU research results applicable in building sector, the Club offers to market operators:

- an innovative procedure for analysing market potentiality of research results and eco-sustainable building concepts in an international ambit;
- the opportunity for having a qualified and direct contact with worldwide high level experts in building and energy sectors;
- the possibility to promote one's own research results through project dissemination activities;
- the opportunity to assess the feasibility of some specific technology transferring actions.
- transferring actions.

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Ground Source Heat Pump of high Temperature

Pre-prototype development tasks included compressor selection (market survey, selection of compressor supplier), selection of individual components (heat exchangers, back pressure – needle – electronic expansion valve, suction accumulator, piping and fittings, pressure controllers, CO_2 refrigerant, heat pump control, heat pump casing, manufacturing), assembling a CO_2 heat pump pre-prototype delivering 80ºC for heating and domestic hot water supply, assembling a R134a heat pump pre-prototype delivering 80ºC for heating (and domestic hot water supply), as well as defining further technology development requirements.

Next work included perfecting, testing and evaluating two pre-prototypes, one using CO_2 as refrigerant, and one using R134a. The evaluation of the pre-prototypes indicated that only the R134a one is suitable for demonstration in terms of safety aspects, two prototypes of which were developed and manufactured. The unit exhibited COP=2,2 for high temperature heating at 80/60°C. Future applications should include controlling the heating temperature according to load, e.g. reduced temperature at partial load, in order to increase the system SPF to levels above 3,0.

Measurements made at the CIAT R&D lab by CIAT personnel under the direction and supervision of CRES, proved the ability of the unit to operate in high temperature heating systems with acceptable COP, as shown in Table 2. Further measurements for low temperature heating at Eurovent floor heating conditions showed that the prototype yields COP=5,54, value still higher than other high efficiency heat pumps available at the market by 8% (Table 2 below).

Testing conditions	Evaporator water temperature		Condenser water temperature		Heating capacity	Input Power without pumps	COP
Eurovent CHF	Inlet (°C)	Outlet (°C)	Inlet (°C)	Outlet (°C)	(kW)	(kW)	
AUREA 2 50 HT	10	*	30	35	16.1	3.12	5.16
High Temp. Prototype	10	7	30	35	14.97	2.7	5.54 (+8%)

Table 2: Laboratory measured performance of the Groundhit high temperature prototype at Eurovent floor heating conditions.

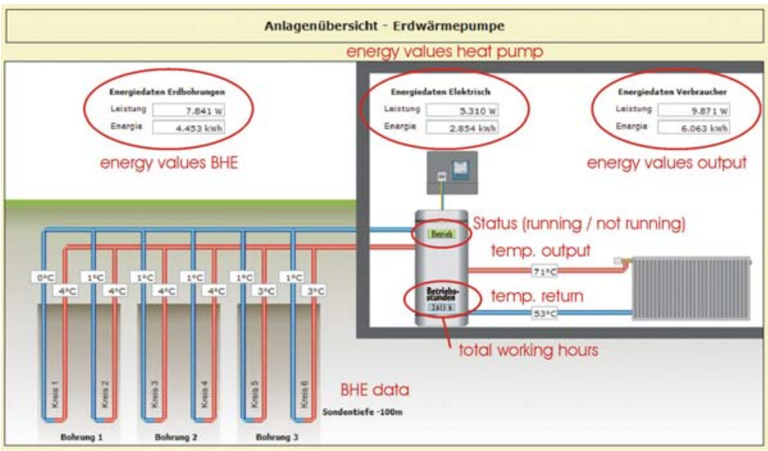

Fig. 5: On line view of monitoring data output showing real time operation parameters of the high temperature Groundhit prototype demonstration at Feistritzwerke-STEWEAG headquarters in Gleisdorf. (web site http://www.feistritzwerke.at/)

The EBC membership will be established through a specific endorsement procedure by the completion of the endorsement questionnaire.

The questionnaire can be downloaded from the project website: http://www.ecobuilding-club.net/downloads/Technology_developers.doc

- If you would like to be included in the project's 'market operator' database, please fill in the form downloadable at: http://www.ecobuilding-club.net/downloads/Market%20operators.doc

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Ground Source Heat Pump for warm Groundwater

Heat pump cycle computer simulations indicated that most refrigerants are capable for achieving the project objective of COP>7,0. Refrigerant selected was R410A . The focus was to widen the evaporation envelope of the compressor, to allow higher evaporation temperatures. For this purpose the ZPS compressor was developed as a joint venture between Copeland compressors manufacturer and CIAT, which is characterised by the ability to operate with higher evaporation temperatures, as shown in Figure 6. Other activities included selecting components for the pre-prototype and integrating domestic hot water supply to the unit, as well as developing, testing and evaluating the final pre-prototype, followed by prototype development and manufacturing two units. These prototypes exhibit superior energy performance with COP in the range of 7,3-8,2 when supplied by groundwater of 25-30°C and delivering 40°C water for heating.
Measurements made at the CIAT R&D lab by CIAT personnel (Figure 8) under the direction and supervision of CRES, proved the superior energy efficiency of the unit (COP=7,3-8,2) when supplied by warm water of 25-30ºC, as shown in Table 3. Additional measurements for low temperature heating at Eurovent floor heating conditions showed that the prototype yields COP=5,87, value higher than other heat pumps available at the market by 14%, even when the machine is supplied by cold water from the ground or from a borehole heat exchanger (Table 3 below).

Testing conditions Eurovent CHF	Evaporator water temperature		Condenser water temperature		Heating capacity (kW)	Input Power without pumps (kW)	COP
	Inlet (°C)	Outlet (°C)	Inlet (°C)	Outlet (°C)			
AUREA 2 50 HT	10	*	30	35	16.1	3.12	5.16
warm water Prototype	10	7	30	35	13.03	2.22	5.87 (+14%)

Table 3: Laboratory measured performance of the Groundhit warm groundwater prototype at Eurovent floor heating conditions.

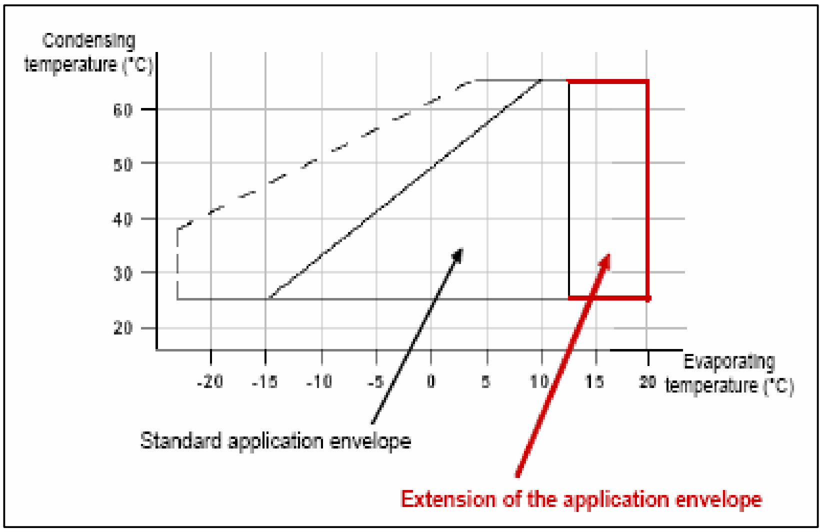

Fig. 6: Condensing and evaporating temperatures envelope of typical heat pumps, and extension made for Groundhit in order to adapt to thermal waters

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Fig. 7: Groundhit heat pump prototype for warm groundwater at the Neo Ryssio demonstration site.

Results and Achievements (specific technical characteristics, performance, economic and environmental aspects, etc.)**:**

The Groundhit project was a successful project in terms of improving cost-effectiveness, competitiveness and market penetration of ground coupled heat pumps by bringing forward and demonstrating the next generation of BHE and heat pumps technology.
BHE technology has been optimised in terms of heat transfer with the earth, and a prefabricated coaxial BHE prototype was developed. Heat pump technology has been advanced in terms of improving energy efficiency by 10-20% compared with market available units, in terms of delivering 80ºC water temperature output for the retrofit and mass markets for high temperature heating, and in terms of ability to utilize warm groundwater with 40% higher efficiency than normal heat pumps.
Two coaxial BHE prototypes are demonstrated at the campus of the Technical University of Setubal, Portugal, showing good energy performance and easy installation. The heat pump prototypes of high efficiency are demonstrated for heating and cooling at the Setubal campus, coupled to 5 BHEs. The high temperature prototype is demonstrated in Gleisdorf, Austria, for heating the headquarters of Feistritzwerke-STEWEAG GmbH, a regional power and heat supplier, coupled to three BHEs. The warm groundwater heat pump prototype is demonstrated for heating, cooling and sanitary hot water production at the Christodoulides tile factory in Neo Ryssio near Thessaloniki, Greece coupled to a warm groundwater well.
Groundhit project confirmed the reliability, ease of installation and durability of BHEs by developing and testing the less common coaxial type. It expanded market prospects and potential impact of heat pumps towards reducing CO_2 emissions by developing stronger products in terms of energy efficiency, temperature output and evaporation envelop. Groundhit heat pump prototypes are in a stronger position than other heat pumps to compete effectively against fossil fuel boilers in all aspects of space heating and domestic hot water market.

Possible application area: Buildings

Reference (EU/national program where the technology has been developed)**:** Sixth Framework Programme – Specific Target Research or Innovation Project, Contract 50363

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Contact person for further information:

Name	Dr. C. Karytsas
Company	CRES
Telephone no.	+30210 6603375
Telefax no.	+30210 6603301/302
E-mail	kkari@cres.gr
Address	19th km Marathonos Ave, 19009, Pikermi Attiki Greece
Web-site	www.cres.gr

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