Monitoring results after 12 months of provision of heating and cooling at the 8 demonstration buildings of the European project "Ground-Med"

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ABSTRACT

A new generation of high efficiency ground source heat pump systems was developed by the GROUND - MED project (1.01.2009 – 31.12.2014). These GSHP systems have been installed and demonstrated in 8 buildings of South Europe. The project was supported by the FP7 program of the European Commission. After two complete seasons of monitoring heating and cooling operation, the project proved that the technological advantage of high efficiency heat pumps can be utilized in its full potential by borehole heat exchangers delivering water at favourable temperature levels (7-20°C in heating and 14-39°C in cooling), low temperature indoor heating system (supplying water of 28-43°C for heating and 7-18°C for cooling) and advanced operation controls synchronizing pumps, fans and compressors while optimizing water supply temperature to the building. Superior seasonal performance factors SPF2 (considering electricity consumption at the compressors and external pump) were achieved, namely 3.63-5.91 in heating, 4.87-6.76 in active cooling and 9.80-16.59 in free cooling modes, well above project objectives and the EU average SPF of ground source heat pumps.

1. INTRODUCTION

The Ground-Med project "Advanced ground source heat pump systems for heating and cooling in Mediterranean climate" developed, demonstrated and monitor eight integrated advanced ground source heat pump (GSHP) systems of seasonal performance factor SPF (defined as the ratio of useful heating and cooling delivered by the heat pump divided by the electricity consumed) higher than 5.0 compared to an average of SPF2=3.5 of present GSHPs installed in EU.

The project commenced on 1 January 2009 and lasted for 6 full years until 31 December 2014. Its budget was around 7.2 million euro, 4.3 million euro of which was financed by the 7th Framework Programme for Research and Technological Development (FP7) of the European Commission through grant agreement No TREN/FP7EN/218895.

Originally it started as an initiative of the European Heat Pump Association (EHPA), which now hosts the project website http://www.groundmed.eu/, which invited the Centre for Renewable Energy Sources (CRES) to assemble the consortium and develop the project.

Ground-Med ideas were based on the results of three previous successful European projects on heat pumps technology development and demonstration, namely on Groundhit coordinated by CRES, which had improved the energy efficiency of ground source heat pumps (GSHP) and had developed a coaxial borehole heat exchanger (BHE), Sherpha coordinated by CETIAT, which had developed several heat pumps using natural fluids as refrigerants, and GeoCool, coordinated by University Polytechnic of Valencia (UPV), which had demonstrated the superior efficiency of GSHP used for cooling compared to air source heat pumps.

Ground-Med project was implemented by a consortium of 24 organisations based in EU, coordinated by CRES, as shown in Table 1 at the end of this paper. They included a wide diversity of GSHP actors, such as research and educational institutes, heat pump manufacturers, national and European industrial associations, renewable energy consultants and works contractors.

2. TECHNOLOGY DEVELOPMENT

During the Ground-Med project implementation GSHP were considered as an integrated set comprising a BHE field, a water source heat pump and an indoor heating/cooling system, with the project objective to maximize overall energy efficiency.

Although in previous projects the target was the COP improvement, in Ground-Med the technology development focused on the seasonal performance factor (SPF) of the heat pump. For this purpose, special emphasis was given to the capacity control of the heat pump. Different options have been considered including inverter controlled compressors and tandem compressors.

Additional gain in SPF was achieved by maintaining the heat exchangers in counter flow operation during both heating and cooling modes and optimizing evaporation superheat by an electronic expansion valve. Refrigerants used included R410A and R407C depending on the manufacturer.

In addition, other GSHP system components were also developed. They included: (i) advanced fan-coil units with reduced power consumption to 20-25% of their original level; (ii) improved air handling units of low primary energy use in which electric resistance heating was replaced by condensing heat; (iii) advanced heat storage nodules, which allow intraday storage of heat and cool at optimum temperatures for maximum energy efficiency.

Further energy efficiency improvements were achieved by selecting smart water circulating pumps among energy class A brands available from European manufacturers.

Moreover, special effort has been dedicated to the GSHP control system. The objective was to regulate the temperature of both the BHE field and the water supply to the indoor system, in order to force the system to operate with as low temperature difference (ΔT) as possible across the heat pump, which leads to maximum possible SPF1.

In order to achieve this, Ground-Med GSHP systems automatically modified their set point to adjust the water temperature supplied to the building heating and cooling system proportionally to the heating or cooling load. Water supply temperatures to the building were 28-43°C in heating mode and 7-18°C in cooling mode.

In terms of heat pump efficiency, this reduction to heating water temperature supply to the building leads to a considerable COP and SPF improvements translated as 20% less electricity consumption at the heat pump.

Furthermore, additional energy savings were achieved by improving SPF2 by synchronising the operation of the external pump with the compressors, eliminating unnecessary pump operation. This concept was also extended to SPF3 and SPF4 by synchronizing internal pumps and fans operation where possible. This meant that the system was shut down when not needed, e.g. at nights and during weekends. In terms of SPF3, and as at least one pump must be always on to transmit the heating/cooling to the building terminal units, best results were obtained by continuous control of pump speed at optimum levels defined experimentally at each demo site. An extended analysis of Ground-Med control systems is presented in Mendrinos and Karytsas (2013).

Ground-Med BHEs (Fig. 1) were designed and constructed using water as heat transfer fluid and grouting with coarse sand or tiny gravel below the water table level, and with bentonitic seal above it. They delivered water to the heat pump at favourable temperature levels, namely 7-20°C in heating mode and 14-39°C in cooling mode. More details on BHE performance during 12 months of monitoring are presented in Mendrinos and Karytsas (2015).

Finally, as the project targeted the Mediterranean climate regions, cooling was of extreme importance. This posed additional challenges to the BHE design and sizing and set high standards for the heat pump efficiency. As stated in Mendrinos (2010), while poorly designed GSHP systems can still operate fairly well in heating mode although at the expense of energy efficiency, only the best heat pumps in terms of COP coupled to state-of-the-art designed and sized BHEs can provide reliable and cost effective operation in cooling mode.

Figure 1: Drilling borehole heat exchangers by ENEREN at HIREF factory demo site, in Tribano, Padova

3. DEMONSTRATION AND MONITORING

The developed GSHP technology was applied in eight demonstration buildings, where advanced GSHP systems for heating and cooling were constructed, which were monitored for evaluation purposes. System parameters were recorded at each site every minute by a local data logging system (Fig. 2) and were transmitted through the internet via ftp to the main project server located at the University of Coimbra.

Main measuring equipment comprised a set of heat meters connected to the BHE and building water supply loops, as well as a set of electrical energy analysers connected at the compressors, pumps and fans, plus space and ambient temperature sensors.

Then, monitoring data were compiled and debugged, in order to eliminate systematic and random errors, and were presented on-line through the project web site, from where they were available for download by project partners. For technology evaluation purposes four different COP and SPF values were calculated considering electricity consumption at:

- compressor in the case of COP1 and SPF1,
- compressor and external (BHE) circulation pump in the case of COP2 and SPF2,

- compressor and both external and internal circulation pumps in the case of COP3 and SPF3 and,
- compressor, all pumps, fan-coils and air handling units in the case of COP4 and SPF4.

COP1 and SPF1 measure the energy efficiency of the heat pump itself. COP2 and SPF2 are for comparison with other technologies, as the external pump is a unique feature of the ground source systems. COP3 and SPF3 measure the efficiency of the hydraulic system. COP4 and SPF4 measure the overall efficiency of the entire heating/cooling system.

Figure 2: Ground-Med heat pump and local data logging system at Coimbra Regional Authority building

4. RESULTS

Ground-Med technology development included new prototypes which were integrated into 8 GSHP systems demonstrated and monitored at 8 buildings of South Europe.

Three advanced heat pump prototypes in terms of superior energy efficiency were delivered by Austrian manufacturer OCHSNER WP. They included external water reversibility by a set of 4 three-way valves with or without refrigerant circuit reversibility, electronic expansion valves, as well as the option for free cooling provision directly from the borehole heat exchanger.

Two advanced heat pump prototypes were delivered by the Italian manufacturer HIREF: one of tandem compressors and another with inverter compressor, both water side reversible by a set of 2 four-way valves, integrated within the heat pumps case.

Three advanced heat pump prototypes of extraordinary energy efficiency (Eurovent class A) were delivered by the French manufacturer CIAT. Their main features were tandem compressors and water side reversibility by 4 external three-way valves. They were accompanied by a hydraulic kit, which allowed operation in free cooling mode.

New advanced fan-coil unit prototypes were developed by CIAT. They were characterized by low temperature operation utilizing the coanda effect and by extremely low electricity consumption (80% electricity savings).

A new air handling unit prototype was delivered by CIAT. It used heat from heat pump condenser replacing electrical resistors in air dehumidification mode, resulting in ~75% savings in primary energy.

Improved cold storage nodules were delivered by the CIAT subsidiary CRISTOPIA, which were optimized in terms of improved efficiency.

More than 12 months monitoring of above systems indicated superior energy performance, as shown by the corresponding SPF values presented in the next figures (Fig. 3 and Fig. 4).

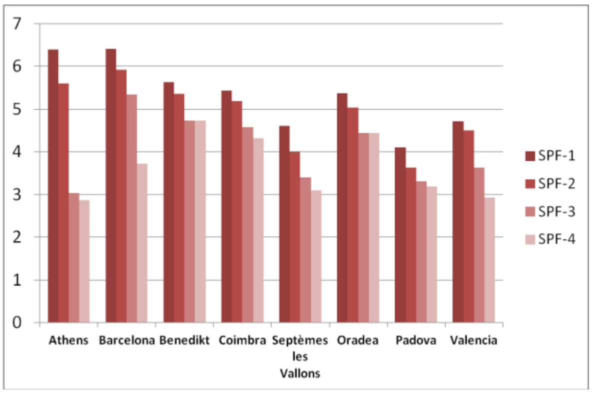

Figure 3: Achieved SPF values at Ground-Med demo sites in heating mode

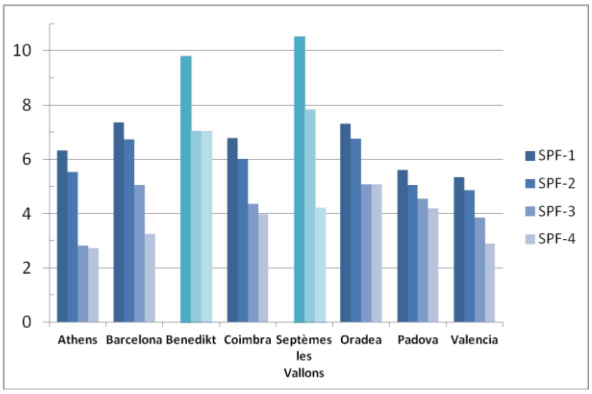

Figure 4: Achieved SPF values at Ground-Med demo sites in active cooling mode (blue bars) and free cooling mode (light blue bars)

5. COST AND ENVIRONMENTAL BENEFITS

The heating and cooling with Ground-Med heat pump systems at the 8 project demo sites resulted in considerable energy savings compared to a conventional systems comprising air source chillers and gas boilers, as shown in Table 2 at the end of the paper.

In summary, and as mentioned in Pardo and Michal (2014), energy savings were 46 - 64% during cooling mode, 77 - 95 % during geocooling (free cooling) mode, and 32 - 55% during heating mode. Annual cost savings were 0.03 to 0.04 €/kWh$_{(th)}$ and CO_2 emissions reduction 0.09 to 0.16 kg per kWh$_{(th)}$.

Ground-Med project confirmed that high efficiency ground source heat pumps (GSHP) are a suitable technology for space heating in buildings contributing simultaneously to the reduction of primary energy consumption and greenhouse gas emissions, to decrease the energy dependency and to the increase the renewable energy share in gross inland consumption. Resulting foregone emissions of greenhouse gases are estimated as 80% CO_2 compared to electrical heating, 72% to diesel oil and 50% emissions reduction compared to natural gas.

In the long run, as Carvalho et al. (2015) concluded, in Europe around 60% of primary energy and 90% of CO_2 emissions can be saved using GSHPs for space heating by the year 2050. Additionally the natural gas dependency of EU can be decreased to 50%, while a contribution of 5.6% to the share of renewable energy sources in the total primary energy use can be achieved by GSHPs.

6. CASE STUDY: COIMBRA REGIONAL AUTHORITY ADMINISTRATION BUILDING

In the Coimbra regional Authority administration building the top floor was renovated and existing air source heat pump system was replaced by the Ground-Med GSHP system. The floor thermal energy needs were 34 kW heating and 48 kW cooling.

One of the large capacity Ground-Med prototype heat pumps was installed at the basement, which had a capacity of 68 kW with both compressors in operation.

The heat pump supplied roof fan-coils as terminal heating and cooling devices, which were developed during the project and were characterized by very low electricity consumption and by their ability to provide thermal comfort delivering air of relatively low temperature, namely around 35 °C, when standard fan-coil supply temperatures are 45 °C.

The heat pump was coupled to a ground heat exchanger consisting of 7 BHEs of double-U type, 125m deep each. The ground heat exchanger supplied the heat pump with water of 16 °C in winter and 20 °C in the summer.

The GSHP system was able to provide heating in winter, free cooling directly from the earth in spring and active cooling in summer. Its layout is presented schematically in Fig. 5, while its energy performance during one year of monitoring is shown in Fig. 6.

During the heating season which started on 19 November 2013 and ended on 21 April 2014, the Ground-Med heat pump delivered 26.18 MWh$_{th}$ to the building top floor. Heating power delivered to the fan-coils in a typical day was in the range 10-50 kW$_{th}$, with water supply temperature 35-40 °C.

Between 9-22 May 2014 free cooling directly from the ground heat exchanger was provided to the building top floor, delivering 0.56 MWh$_c$ of cooling. The temperature supplied by the ground heat exchanger to the fan-coils was 18-19 °C, while cooling capacity varied between 2-11 kW$_c$.

The heat pump started again on 27 June 2014 and cooled the building top floor until 10 September delivering 9.02 MWh$_c$ of cooling. Cooling temperature delivered to the fan-coils in a typical day was in the range 8-13 °C, while cooling capacity was in range 5-40 kW$_c$.

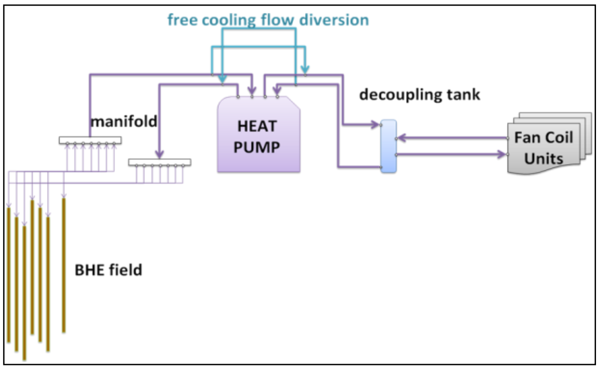

Figure 5: Coimbra Ground-Med GSHP system configuration.

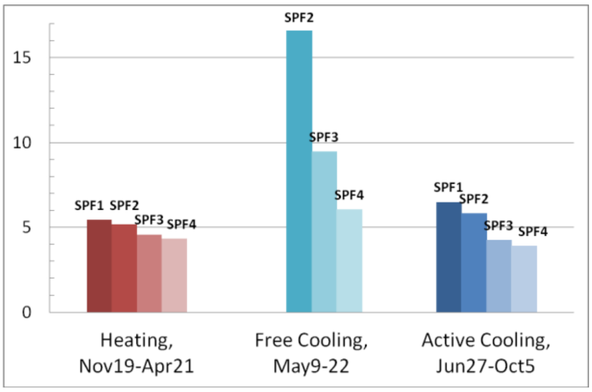

Figure 6: SPF values in Coimbra demo site observed during one complete heating and one complete cooling season, from 19 November 2013 to 5 October 2014

7. CONCLUSIONS

The Ground-Med project developed 8 new heat pump prototypes incorporating advanced solutions for extraordinary energy efficiency, advanced low temperature fan-coil unit prototypes of extremely low electricity consumption, an air-handling unit prototype utilizing condensing heat, thermal storage units, advanced control algorithms, as well as local data acquisition systems and centralized data management system for effective monitoring. The BHEs designed and constructed, deliver advantageous temperatures to the heat pump, allowing improved energy performance. Monitoring of the eight project demonstration sites during one cooling and one heating season shows seasonal performance factors (SPF) well above typical GSHP systems in operation.

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Table 1: Ground-Med consortium

Partner	Business activity	Main role in the project
Centre for Renewable Energy Sources and Saving (CRES)	Research centre and energy agency	Coordinator, development of heat pumps, BHE, monitoring system, data debugging and processing, dissemination
CIAT	HVAC systems manufacturer	Heat pumps, FCU and AHU technology development and demonstration
HIREF	HVAC systems manufacturer	Heat pumps technology development and demonstration
OCHSNER	Heat pumps manufacturer	Heat pumps technology development
University of Coimbra - ISR	University	Monitoring and data management system development, national workshop
University of Oradea	University	Demo site development and operation, local seminar
GEJZIR	Geothermal systems contractors	Demo site development and operation, local seminar
ECOSERVEIS	Renewable energy consultants	Demo site development and operation
EDRASIS – Ch. Psallidas	Works contractors	Demo site development and operation
ENEREN	GSHP installers	Demo GSHP design and installation
University College Dublin	University	GSHP control system development
University of Padova	University	Heat pumps technology development, national workshop
University Polytechnic of Valencia	University	COP optimization algorithms and demo site development and operation
CEA	Research centre	Advice on heat exchangers and fluids
GRETh	Heat exchangers association	European conference
Institute Polytechnic of Setubal	University	Heat pumps technology development
KTH – Royal Institute of Technology	University	BHE technology development
GEOTEAM	Geothermal works contractors	BHE design and construction
BESEL	Liquidated	Data management specifications, seminar
GROENHOLLAND	GSHP installers	BHE technology development
CETIAT	HVAC industrial technical centre	Technology evaluation, national workshop
FIZ	Information centre	Web site design and maintenance
EHPA	European heat pumps association	Dissemination
EGEC	Geothermal industry federation	BHE design, European conference

Table 2: Cost savings and CO_2 emissions reduction at the Ground-Med demo sites

Demo site	GSHP capacity, kW	Heating needs, MWh	Cooling needs, MWh	GSHP annual electricity bill, €	GSHP annual CO_2 emissions, ton	Air source + gas annual energy bill, €	Air source + gas annual CO_2 emis-sions, ton
Barcelona (Spain)	70	68.09	5.42	2739	3.02	5646	13.65
Oradea Campus (Romania)	37	96.97	5.71	2516	16.89	2941	20.23
Benedikt (Slovenia)	24	40.89	0.66	1165	5.71	2763	8.26
Septèmes les Vallons (France)	26	31.37	4.15	1194	0.65	2350	6.32
Tribano, Padova (Italy)	14	28.17	9.14	1939	3.57	3212	7.00
Coimbra (Portugal)	68	86.59	4.94	3715	7.27	7742	17.74
Valencia Poly Campus (Spain)	18	10.36	5.20	775	0.85	1243	2.50
Near Athens airport (Greece)	65	84.31	75.34	4759	18.69	10743	32.24

Source: Pardo, P., and Michal, H. (2014).