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Results of EU Project Ground-Med concerning Advanced Ground Source Heat Pump Systems for Heating and Cooling

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ABSTRACT

The Ground-Med project "Advanced ground source heat pump systems for heating and cooling in Mediterranean climate" concerned the development, demonstration and monitoring of prototype ground source heat pump (GSHP) systems in eight buildings of South Europe. The main objectives were to develop a new generation of ground source heat pump systems with maximum possible measured seasonal performance factors and demonstrate them during heating and cooling operation in 8 buildings of South Europe.

The project was implemented by a consortium of 24 European organizations, including the European heat pump manufacturers CIAT, HIREF and OCHSNER WP, and coordinated by the Centre for Renewable Energy Sources and Saving (CRES). It started on 1 January 2009 and ended on 31 December 2014. It had a budget of approximately 7.24 million euro, 4.3 million of which was provided by the EU, through the FP7 program. More information about the Ground-Med project, including GSHP applications and news, is provided at the project internet site, at the web address: http://www.groundmed.eu/.

The 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 equipment, advanced control algorithms, as well as local data acquisition systems and centralized data management system for effective monitoring. Monitoring results demonstrated SPF values above 5 in both heating and cooling modes, values well above the default value of 3.5 for GSHP systems considered as the EU average by the European Commission (2013).

1. INTRODUCTION

The Ground-Med project "Advanced ground source heat pump systems for heating and cooling in Mediterranean climate" concerned the development, demonstration and monitoring of prototype ground source heat pump (GSHP) systems in eight buildings of South Europe. The main objective was to demonstrate maximum possible measured seasonal performance factors during heating and cooling operation. The project was implemented by a consortium of 24 European organizations and coordinated by the Centre for Renewable Energy Sources and Saving (CRES) of Greece. It started on 1 January 2009 and ended on 31 December 2014. It had a budget of approximately 7.24 million euro, 4.3 million of which was the EU funding, through the FP7 program. The members of the Ground-Med consortium follow:

- Centre for Renewable Energy Sources and Saving - CRES, (Greece) as project coordinator,
- Compagnie Industrielle d'Applications Thermiques –CIAT (France),
- HIREF spa (Italy),
- OCHSNER Wärmepumpen GmbH (Austria),
- Institute of Systems and Robotics - University of Coimbra (Portugal),
- University of Oradea (Romania),
- Gejzir Consulting (Slovenia),
- Ecoserveis (Spain),
- Edrasis – Ch. Psallidas SA (Greece),
- Eneren srl (Italy),
- University College Dublin (Ireland),
- Università degli Studi di Padova (Italy),
- Universidad Politécnica de Valencia (Spain),
- Commissariat à l'Énergie Atomique - CEA (France),
- Groupement pour la Recherche sur les Echangeurs Thermiques - GRETh (France),
- Instituto Politecnico de Setubal (Portugal),
- KTH – Royal Institute of Technology (Sweden),
- Geoteam GmbH (Austria),
- Groenholland BV (Netherlands),
- Besel SA (Spain),
- Centre Technique des Industries Aérauliques et Thermique – CETIAT (France),
- Fachinformationszentrum Karlsruhe GmbH – FIZ (Germany),
- European Heat Pump Association - EHPA,
- European Geothermal Energy Council - EGEC.

More information about the Ground-Med project, including applications and news concerning GSHPs, is provided at the project internet site, at the web address: http://www.groundmed.eu/.

2. TECHNOLOGY DEVELOPED

Ground-Med project resulted in the development of new products which have been or will be shortly introduced into the market. They are:

- Three advanced heat pump prototypes of CIAT of extraordinary energy efficiency (Eurovent class A). Their main features are tandem compressors and external water reversibility by 4 automated three-way valves. They are accompanied by a hydraulic kit (also marketed) allowing free cooling operation.
- Two advanced heat pump prototypes of HIREF: one of tandem compressors and another with inverter compressor; both are water side reversible by a set of 2 automated four-way valves placed within the heat pump case.
- Three heat pump prototypes of OCHSNER WP of improved energy efficiency. Their features include external water reversibility by a set of 4 three-way valves with or without internal refrigerant loop reversibility, as well as the option for free cooling provision directly from the borehole heat exchanger.
- New advanced fan-coil unit prototypes of CIAT. They are characterized by low temperature operation utilizing the Coanda effect and by extremely low electricity consumption (80% electricity savings).
- New air handling unit prototype of CIAT. It uses heat from heat pump condenser replacing electrical resistors in air dehumidification mode, resulting in ~75% savings of primary energy.
- Improved cold storage product of CIAT subsidiary CRISTOPIA, optimized for better efficiency.

In addition, improved engineering design and completion practices have been developed for application at the project demonstration sites, which result in superior overall energy efficiency. They include more borehole heat exchanger (BHE) meters than standard design, water as heat transfer fluid at the earth loop, BHE grouting with coarse sand or tiny gravel in the water table and bentonite on top until the surface, as well as design temperatures relaxed from standard engineering practice, in terms of adopting lower peak values in heating mode and higher in cooling mode, as well as variable temperature operation depending on the thermal load (temperature compensation), further improving energy efficiency.

Furthermore, new control algorithms have been developed, which integrate temperature compensation, variable speed control at the water circulating pumps, as well as pumps operation concurrent to the heat pump compressors and/or thermal load. These algorithms have been incorporated within the heat pumps controller software.

3. DEMONSTRATION SITES

Above technologies are being demonstrated in integrated GSHP heating and cooling systems installed at eight buildings in South European countries. Their locations are shown in Figure 1, while their main features in Table 1.

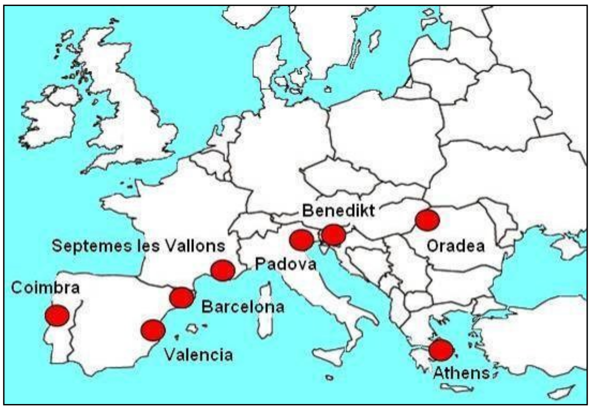

Figure 1: Location of Ground-Med demonstration buildings.

Each demonstration system has been monitored by data sampling every 15 seconds, averaging every minute and sending the data to the project server in Coimbra, where they are debugged from random errors and stored. From there they are available for download through the World Wide Web. Monitored parameters include temperatures, pressures, flows, thermal or cooling power and energy delivered at the BHE, building and sanitary water loops, electricity consumption (both power and energy) at the compressors, pumps and fans, as well as ambient and indoor space temperatures.

Table 1: GROUND-MED project demonstration sites

Location	Description	Peak load (kW)	Heat pump type	Indoor heating-cooling system	Field of borehole heat exchangers
Barcelona (Spain)	Renewable energies demonstration building	70	Tandem compressors	Air handling unit	7 x 110m deep, single-U
Oradea Campus (Romania)	Visual arts faculty building	37	On-off single compressor	In-wall PE pipes	10 x 130m deep, single-U
Benedikt (Slovenia)	Municipal cultural centre	24	On-off single compressor	Radiators	3 (98m, 126m, 166m deep), double-U
Septèmes les Vallons (France)	Office building	26	Tandem compressors	Fan coil units; air handling unit; cold storage	6 x 100m deep, double-U
Tribano, Padova (Italy)	Factory building	14	Inverter compressor	Floor fan coil units; sanitary hot water	4 x 80m deep, 2 single-U, 2 double-U
Coimbra (Portugal)	Regional administration building, top floor offices	68	Tandem compressors	Ceiling fan coil units	7 x 125m deep, single U
Valencia Poly Campus (Spain)	Office building, computer room, facilities room	18	Tandem compressors	Fan coil units	6 x 50m deep, single-U
Near Athens airport (Greece)	Management offices	65	On-off single compressor	Floor fan coil units	12 x 107m deep, double-U

4. PERFORMANCE OF BOREHOLE HEAT EXCHANGERS

In all demonstration sites borehole heat exchangers (BHEs) we able to deliver the fluid temperature levels needed to ensure efficient operation of the heat pump, in the range 7-15 °C under peak heating load conditions in winter, and in the range 17-37 °C during peak cooling load in summer. Temperature transients at the BHEs of the project demonstration sites of Barcelona, Oradea, Benedikt, Septèmes-les-Vallons and Padova are presented in Figures 2 to 16.

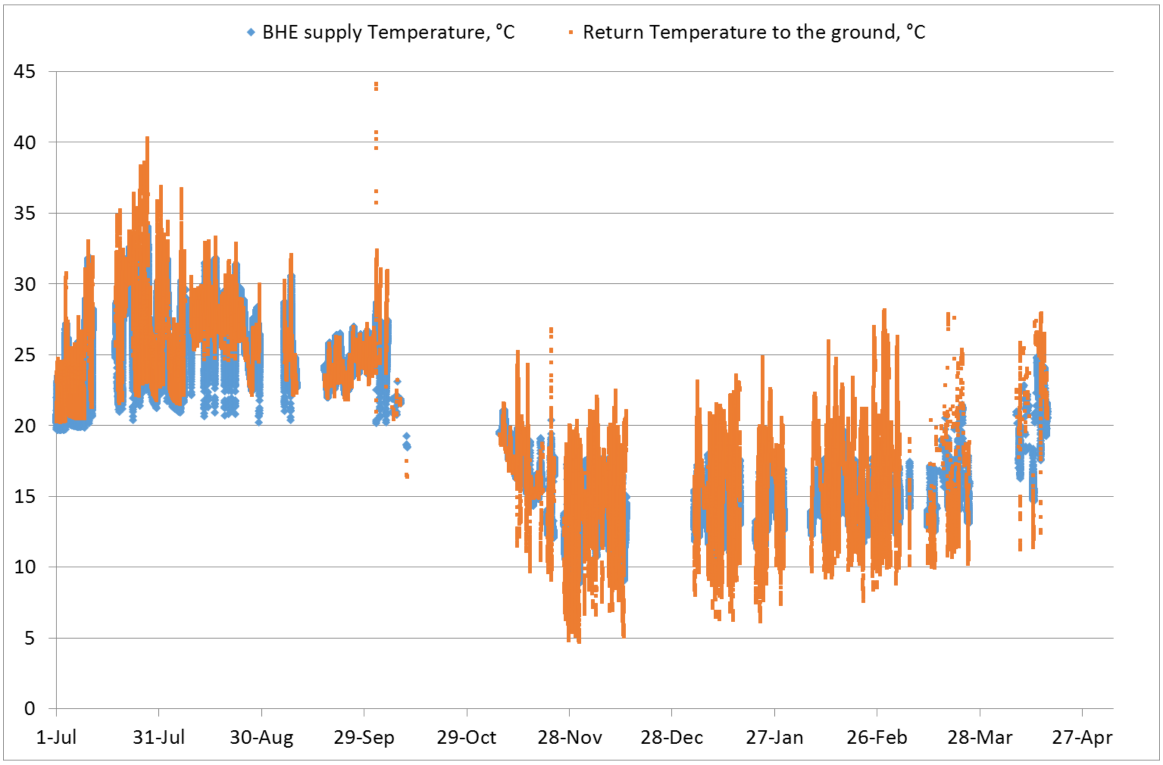

Figure 2: BHE water temperatures at the Barcelona demonstration site, as recorded by the Ground-Med monitoring system.

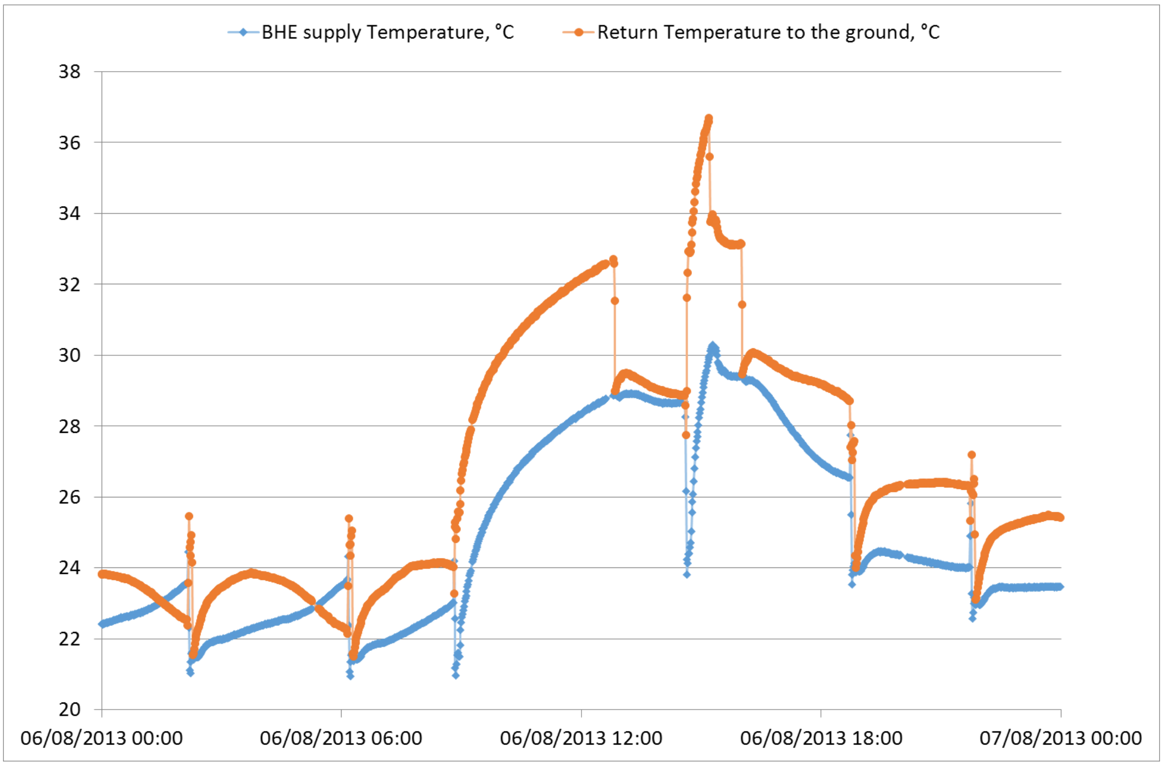

Figure 3: Detail of BHE water temperature at the Barcelona demonstration site in cooling mode: the heat pump operates only during working hours; one compressor is ON in the morning, while two compressors are ON in late afternoon, resulting in the observed higher temperatures and steep temperature rising curve.

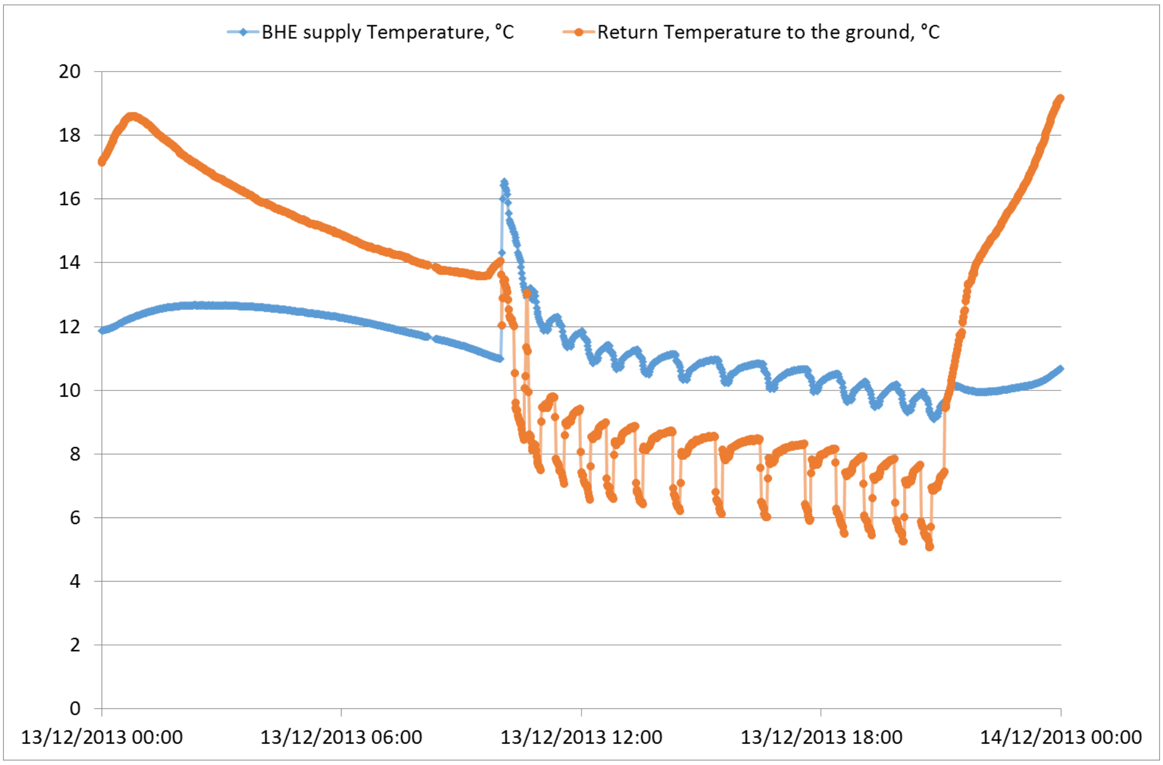

Figure 4: Detail of BHE water temperature at the Barcelona demonstration site in heating mode: the heat pump operates only during working hours; after the initial heat-up period, downward temperature curve and big gap between BHE supply and return temperature corresponds to periods when two compressors are ON, while upward temperature and smaller gap between BHE supply and return temperature corresponds to periods when only one compressor is ON.

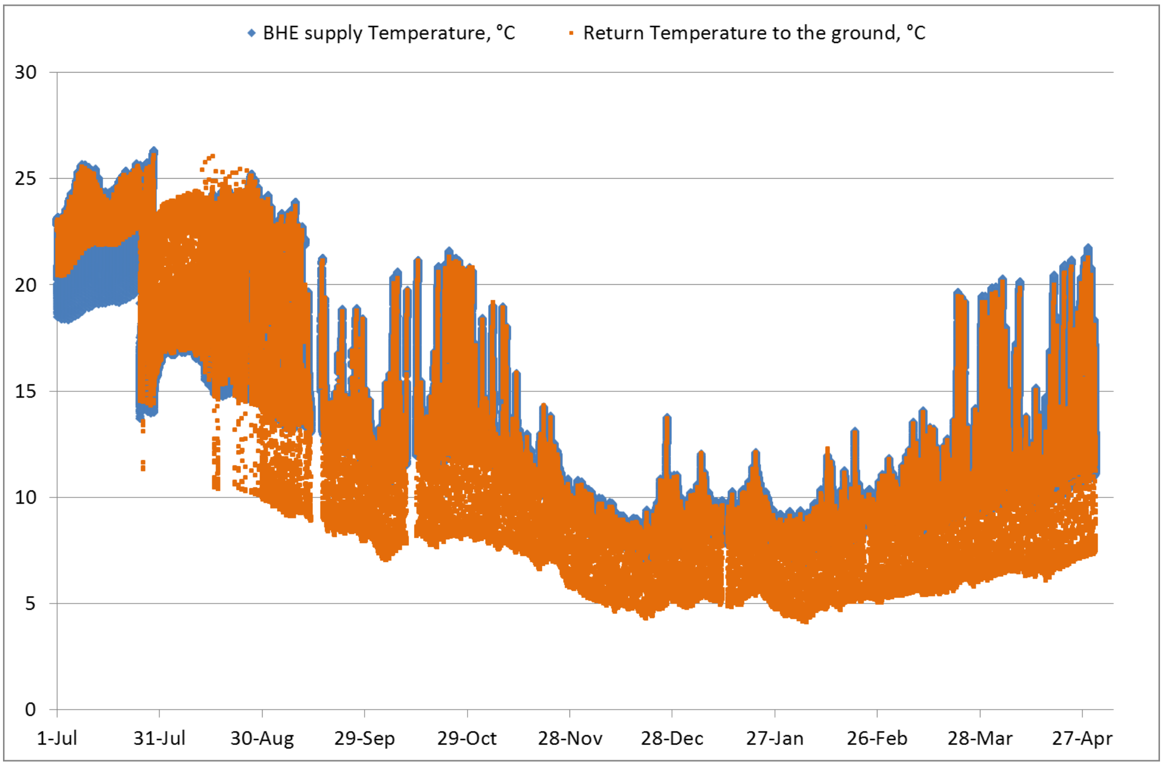

Figure 5: BHE fluid temperatures at the Oradea demonstration site, as recorded by the Ground-Med monitoring system.

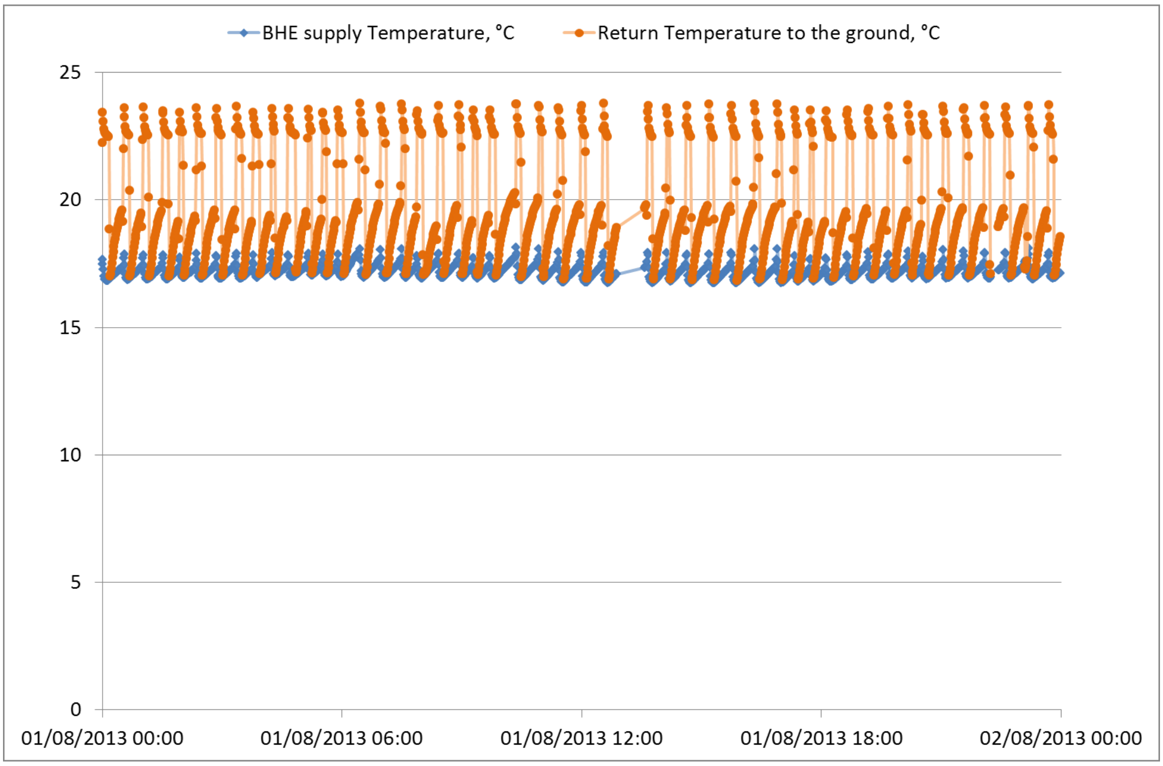

Figure 6: Detail of BHE fluid temperature at the Oradea demonstration site in cooling mode: the heat pump operates continuously by providing cold water to the building wall cooling system at a temperature within a specified range; the upper part of the line corresponds to periods when the compressor is ON.

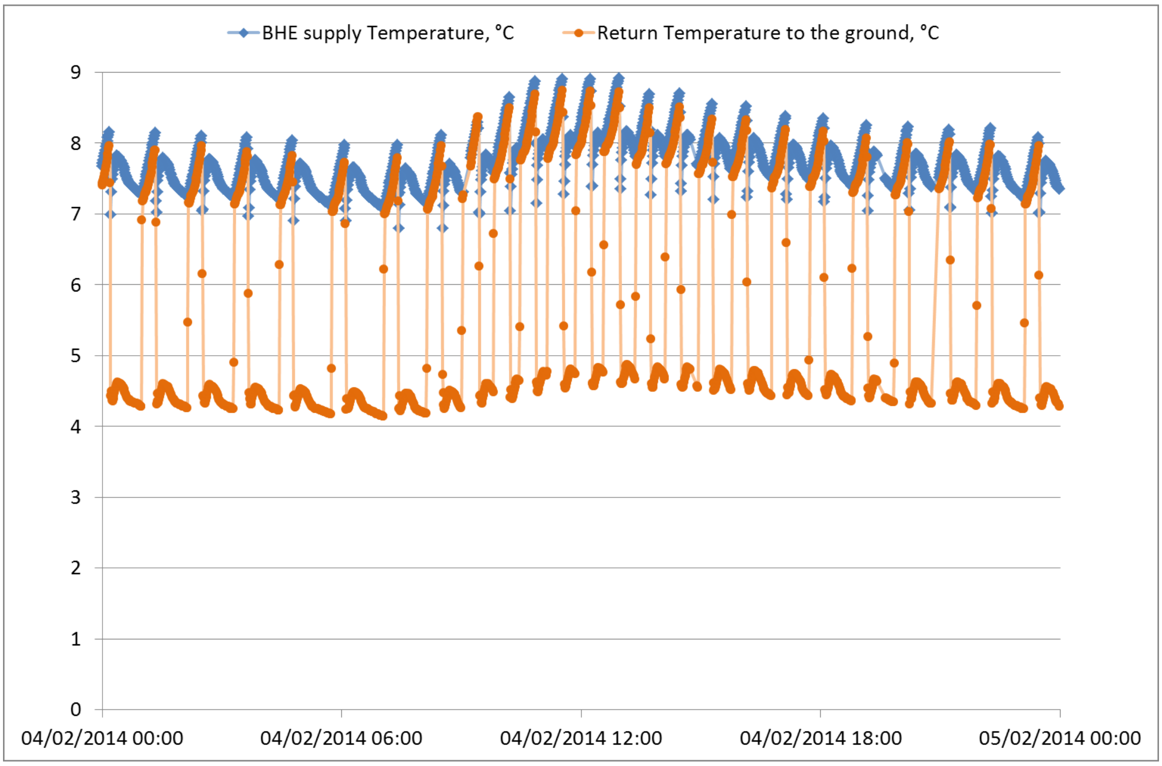

Figure 7: Detail of BHE fluid temperature at the Oradea demonstration site in heating mode: the heat pump operates continuously by providing warm water to the building in-wall heating system at a temperature within a specified range; the lower part of the line corresponds to periods when the compressor is ON.

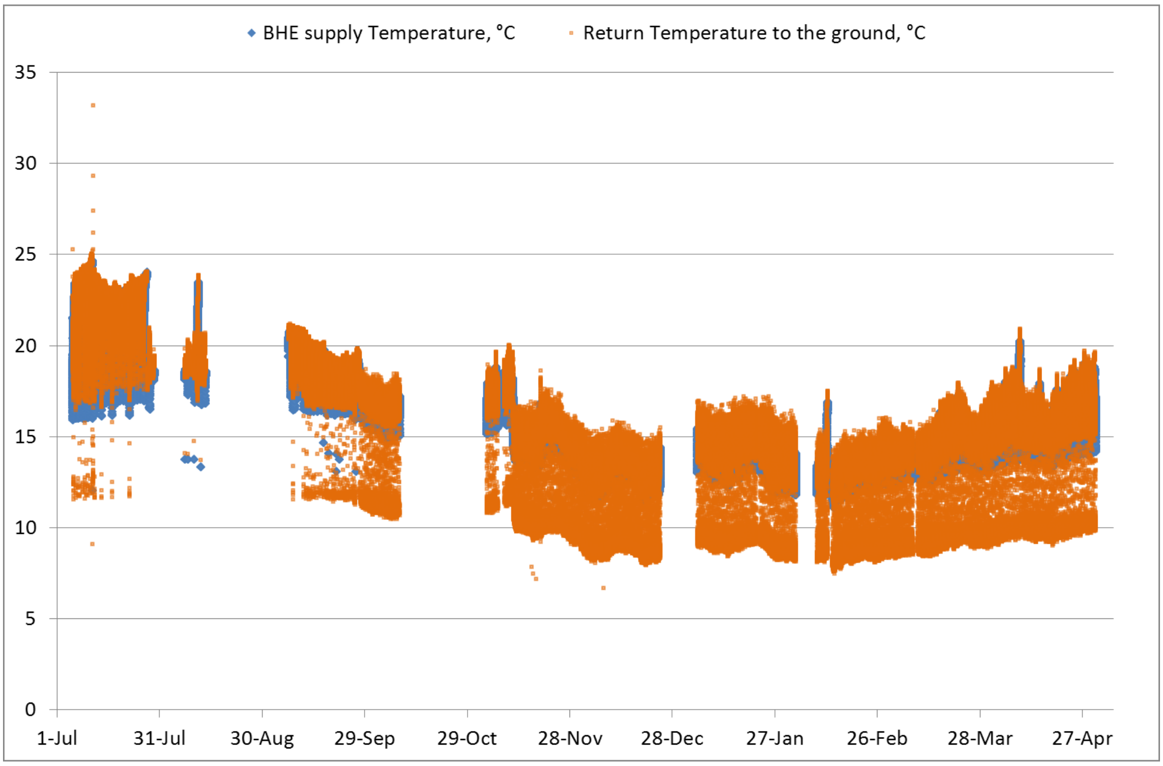

Figure 8: BHE water temperatures at the Benedikt demonstration site, as recorded by the Ground-Med monitoring system. The heat pump operates in free-cooling and heating modes during summer and winter respectively.

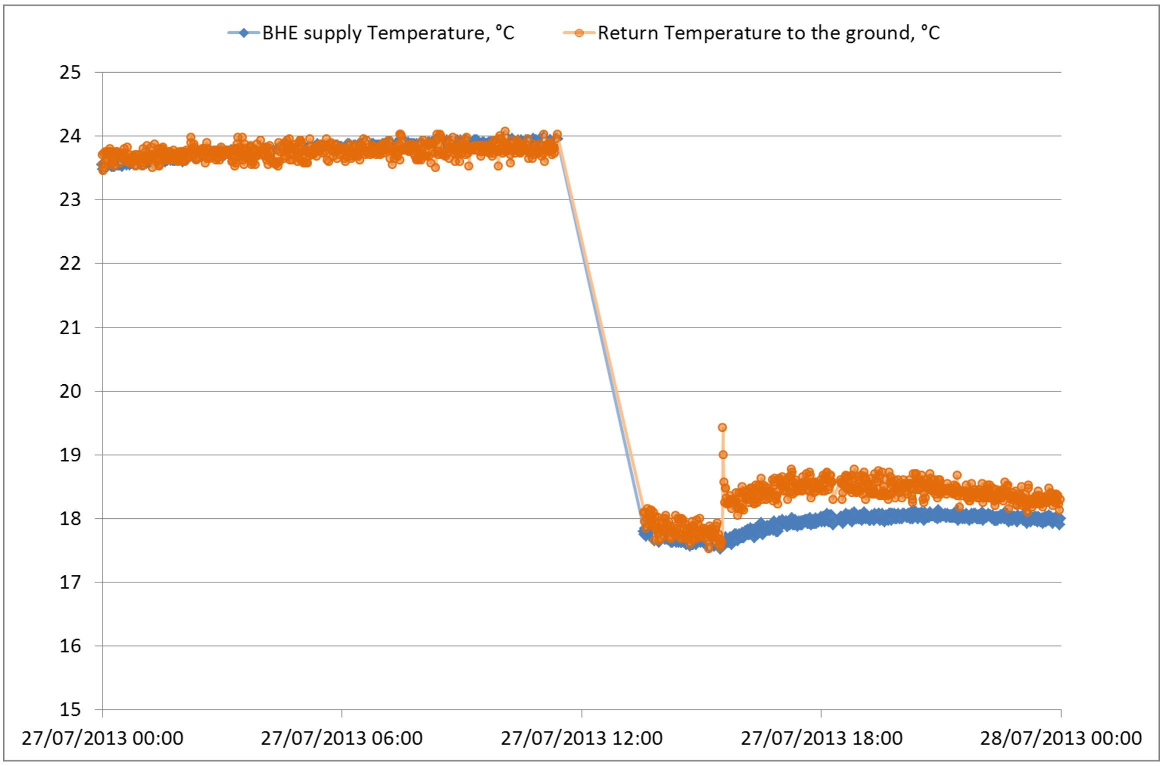

Figure 9: Detail of BHE water temperature at the Benedikt demonstration site in free-cooling mode: the water from the BHE is delivered directly to the radiators installed in the building; free-cooling is provided during the second half of the day with capacity in the range 1-2 kWc.

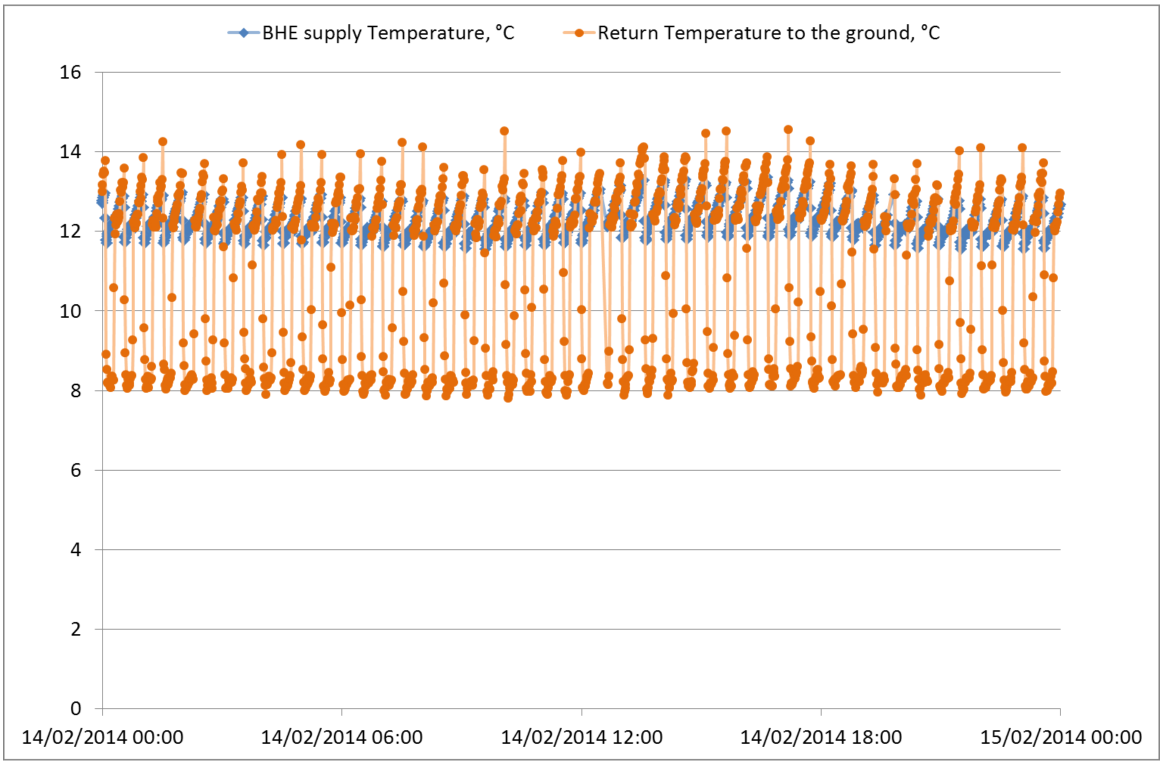

Figure 10: Detail of BHE water temperature at the Benedikt demonstration site in heating mode: the heat pump operates continuously by providing warm water to the radiators at a temperature within a specified range; the lower part of the line corresponds to periods when the compressor is ON.

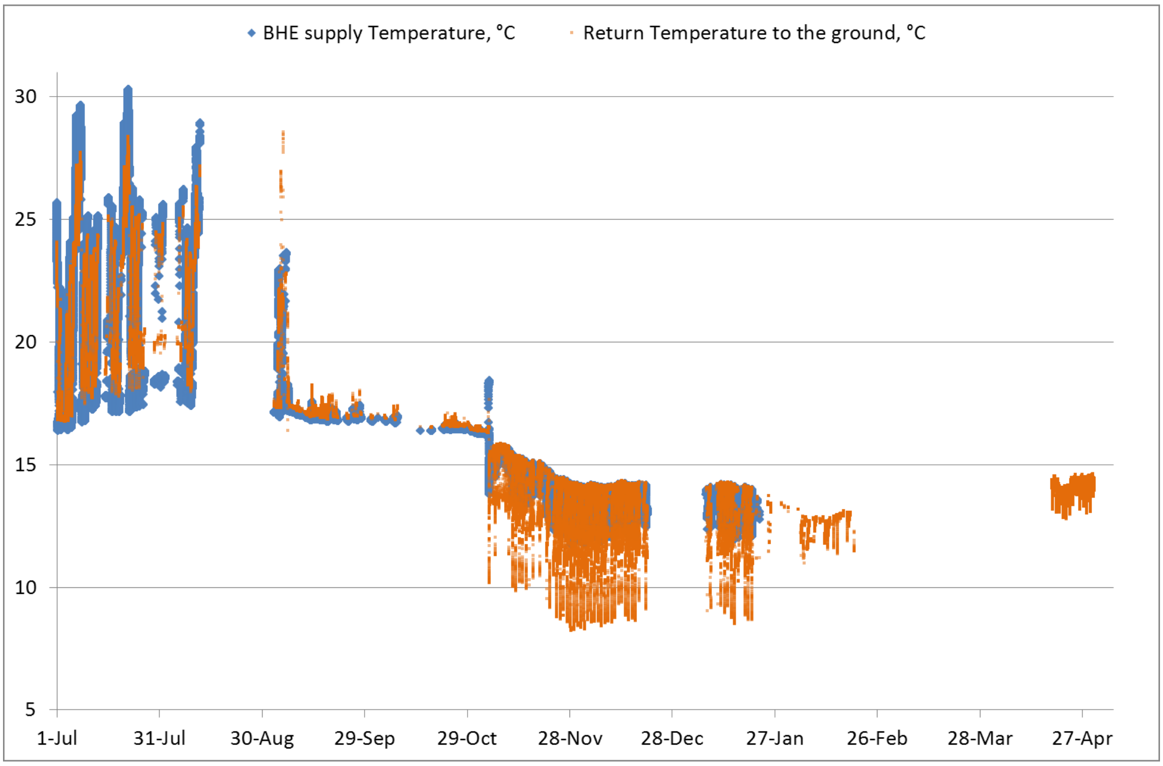

Figure 11: BHE water temperatures at the Septèmes-les-Vallons demonstration site, as recorded by the Ground-Med monitoring system. The heat pump operates in free-cooling mode during summer and in heating mode during winter.

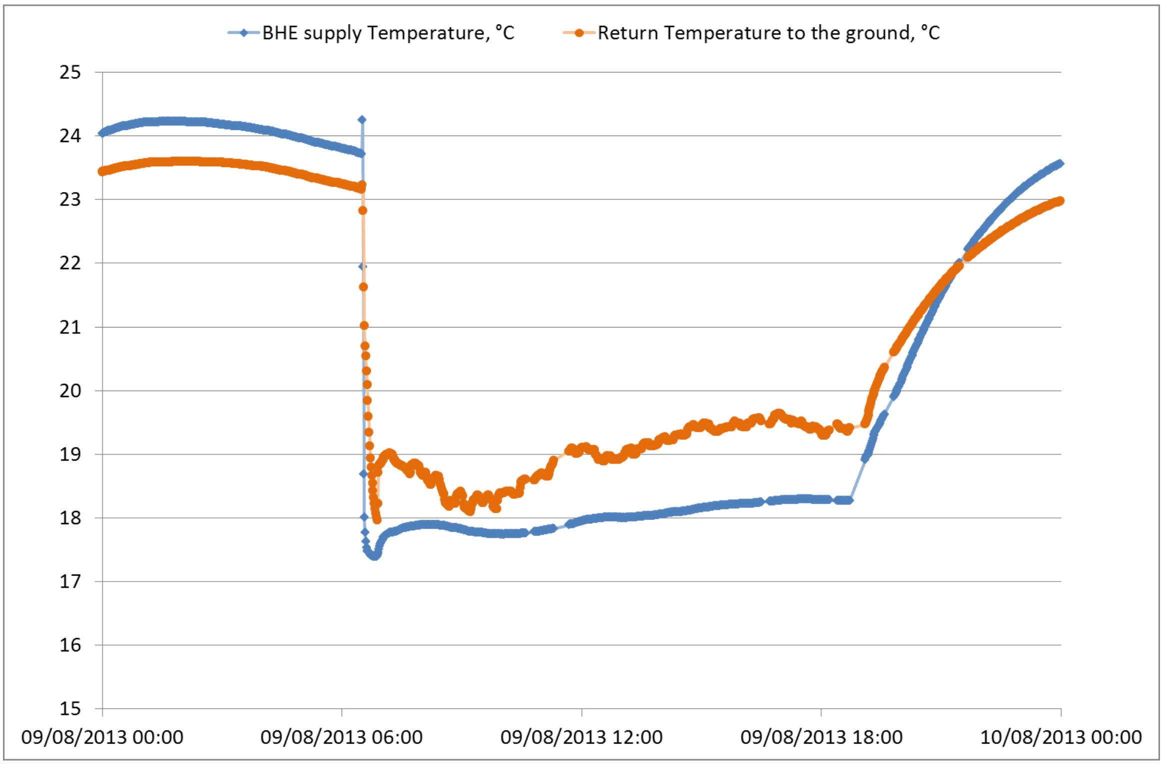

Figure 12: Detail of BHE water temperature at the Septèmes-les-Vallons demonstration site in free-cooling mode: the water from the BHE is delivered directly to the fan-coil units installed in the building; free-cooling was provided during working hours with capacity mainly in the range 4-5 kWc.

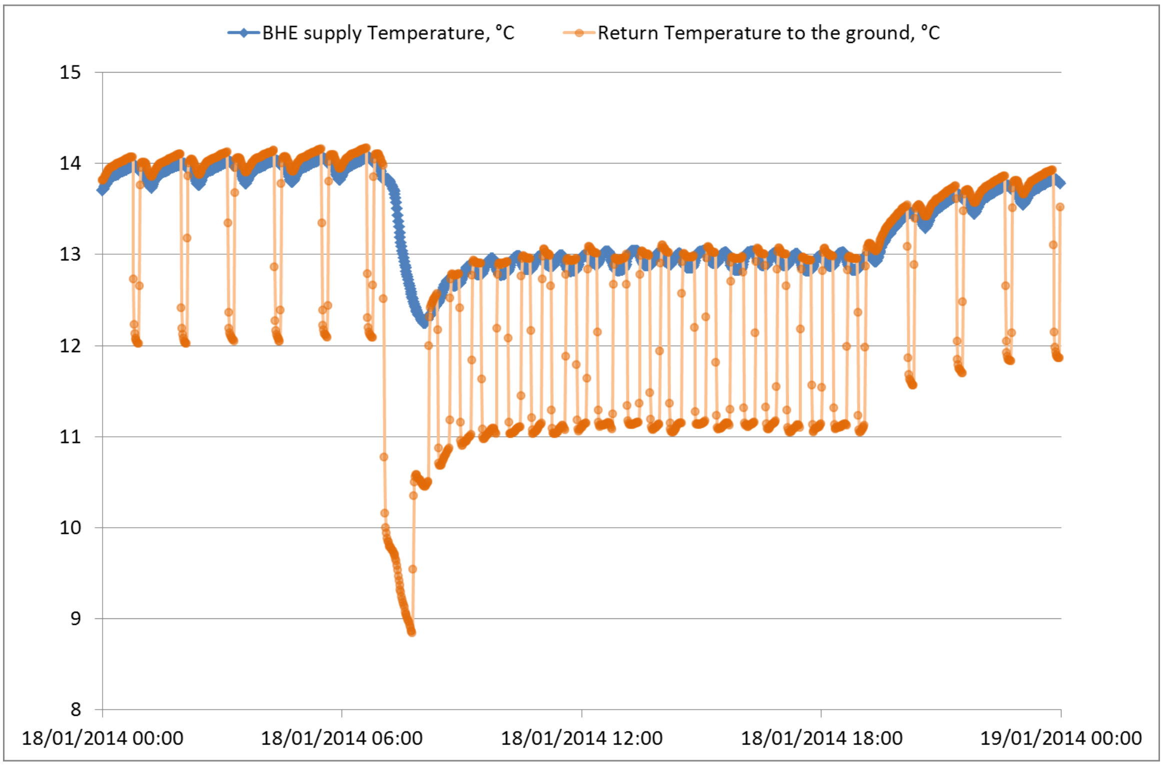

Figure 13: Detail of BHE water temperature at the Septèmes-les-Vallons demonstration site in heating mode: the heat pump maintained a minimum water supply temperature during night, started with two compressors in early morning and continued with one compressor cycling during working hours.

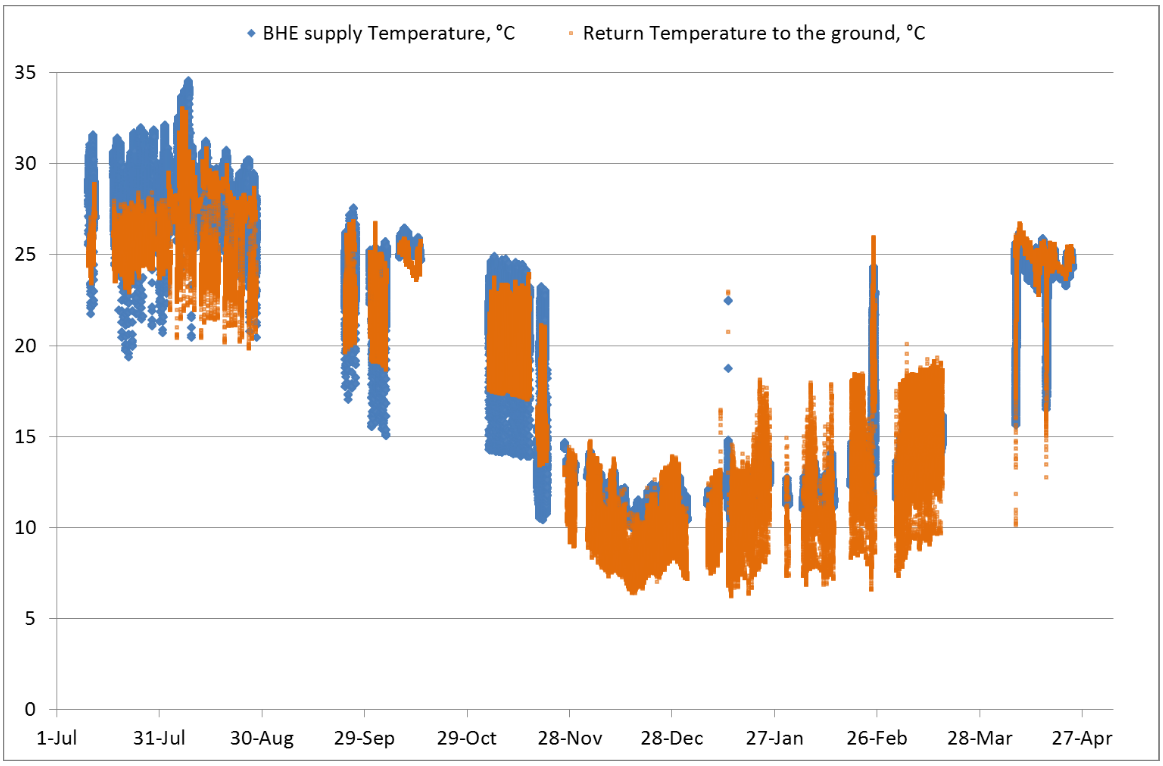

Figure 14: BHE water temperatures at the Padova demonstration site, as recorded by the Ground-Med monitoring system.

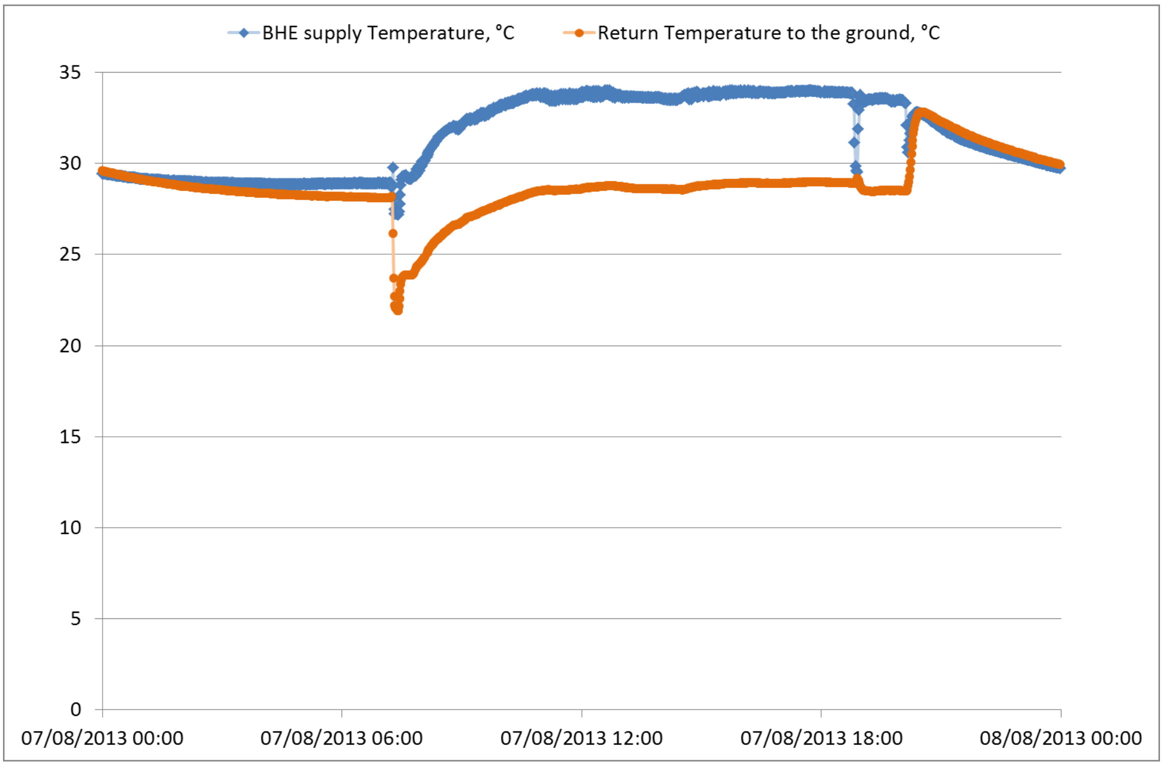

Figure 15: Detail of BHE water temperature at the Padova demonstration site in cooling mode: the system is ON during office working hours; observed smooth temperature transients are attributed to the inverter compressor coupled to inverter pumps; the observed approach between BHE supply and return temperatures occurs when the heat pump unloads heat generated from cooling to the sanitary hot water.

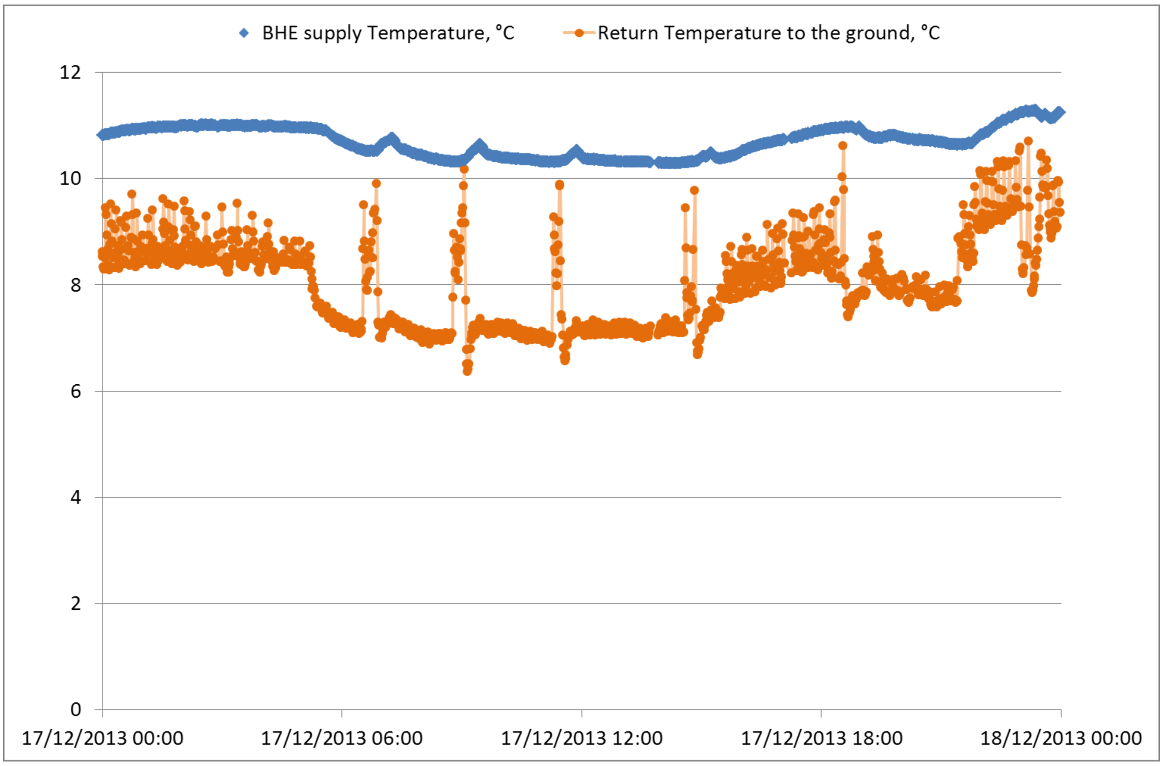

Figure 16: Detail of BHE water temperature at the Padova demonstration site in heating mode: the system is ON during office working hours; observed smooth temperature transients are attributed to the inverter compressor coupled to inverter pumps; the observed approach between BHE supply and return temperatures occurs when the heat pump provides sanitary hot water at higher temperature (45°C instead of 30°C).

5. SYSTEMS ENERGY EFFICIENCY

The instantaneous efficiency of a heat pump is defined by its coefficient of performance (COP), which equals to the ratio of useful thermal power delivered (heat or cool) by the heat pump over the electrical power at a given time. The average COP during a heating or a cooling season is termed as the system seasonal performance factor (SPF). The SPF equals to the useful energy delivered by the heat pump during a time period (heating or cooling season, a whole year, etc.) divided by the electricity consumption during the same period. Depending on which components are considered for the calculation of the electricity consumption, and for the objectives of the Ground-Med project, four (4) levels of COP and SPF were defined as follows:

- COP1, SPF1: only the electricity consumption at the heat pump compressor(s) is considered,
- COP2, SPF2: the electricity consumption at the compressor(s) and the BHE pump are considered,
- COP3, SPF3: the electricity consumption at the compressor(s), the BHE pump and all internal pumps are considered,
- COP4, SPF4: the electricity consumption at the compressor(s), all pumps and fans (FCU & AHU) are considered.

The seasonal performance factors of the project demonstration systems are shown in Figures 17 (cooling) and 18 (heating). SPF1 is a measure of the heat pump energy performance and depends on its components and internal architecture. In general, SPF1 values are more or less optimized, as low temperature heating, high temperature cooling and temperature compensation have already been introduced in all demonstration sites.

SPF2 should be used for comparison with other technologies, as the external pump is unique to ground source heat pumps, while internal pumps and fan-coils are also encountered in other types of heating/cooling systems. The European Commission considers that the typical value for installed GSHPs in EU in heating mode equals to SPFs=3.5, according to the Commission decision 2013/114/EU of 1 March 2013 (European Commission 2013). SPF2 is improved profoundly once the BHE pump operation is optimized in terms of operating only when the compressor is ON, with the necessary safety time lapses of course. Optimizing the BHE pump function, also results in significant improvements in SPF3 and SPF4, due to the profound reduction in electricity consumption in this pump, as demonstrated in all sites.

SPF3 includes all internal pumps in the calculation. Internal pumps are also used in diesel oil, gas fired and biomass systems, solar systems, and others. We included internal pumps, as a considerable part of system electricity consumption takes place there, as they often operate non-stop 24 hours a day. This is particularly relevant to the Ground-Med systems, as the super heat pumps (in terms of energy efficiency) developed earlier in the project resulted in maximum possible SPF1 and extremely low electricity consumption to the compressors, making the electricity consumption in pumps very significant. In order to improve SPF3, energy class “A” variable speed internal pumps have been installed, with the exception of the Athens demo site. Synchronizing the internal pump(s) operation with the compressor effectively improves SPF3, as shown at the sites of Barcelona and Oradea in heating mode. Also turning off internal pumps at nights and weekends when no heating or cooling is required effectively improves SPF3, as shown in Valencia, Barcelona and Athens demo sites. In addition, specific control algorithms developed during the project, result in maximizing SPF3, according to tests performed at Valencia and Coimbra demo sites.

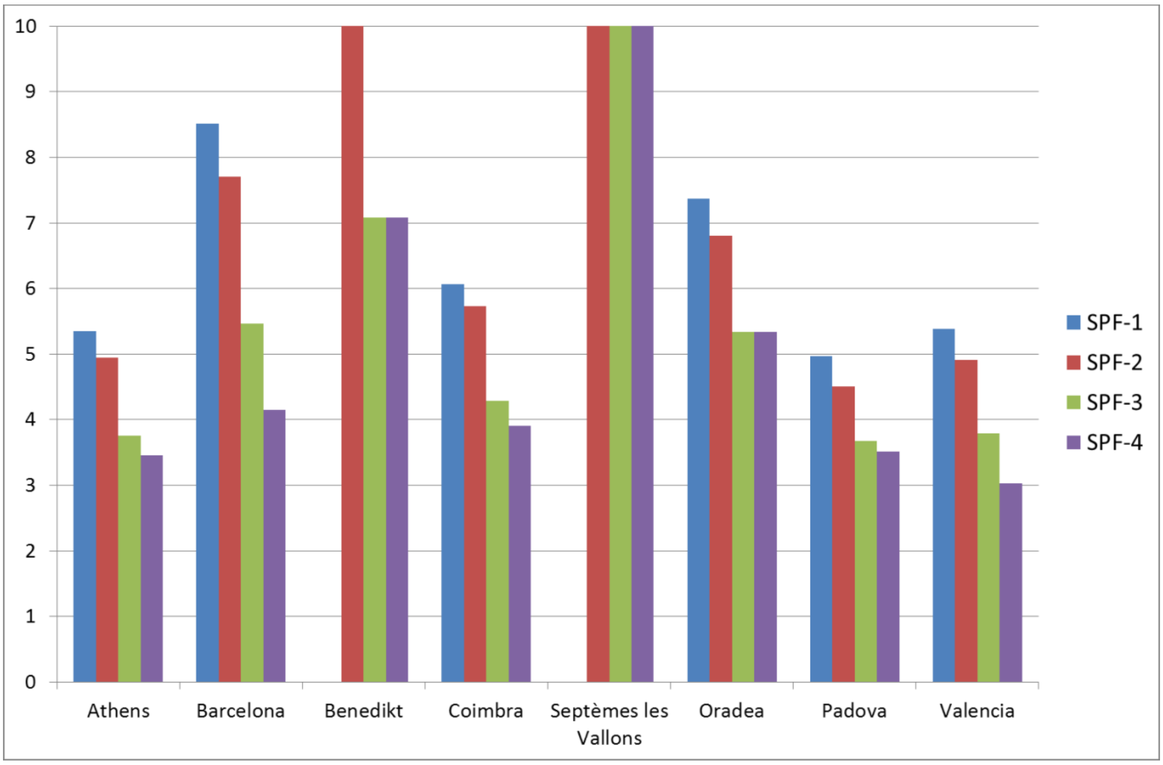

Figure 17: Seasonal performance factors calculated from monitoring data in the project demonstration systems for the cooling season of 2013 (July-September). Free-cooling was provided in Benedikt and Septèmes-les-Vallons (Marseille), while active cooling in all other sites.

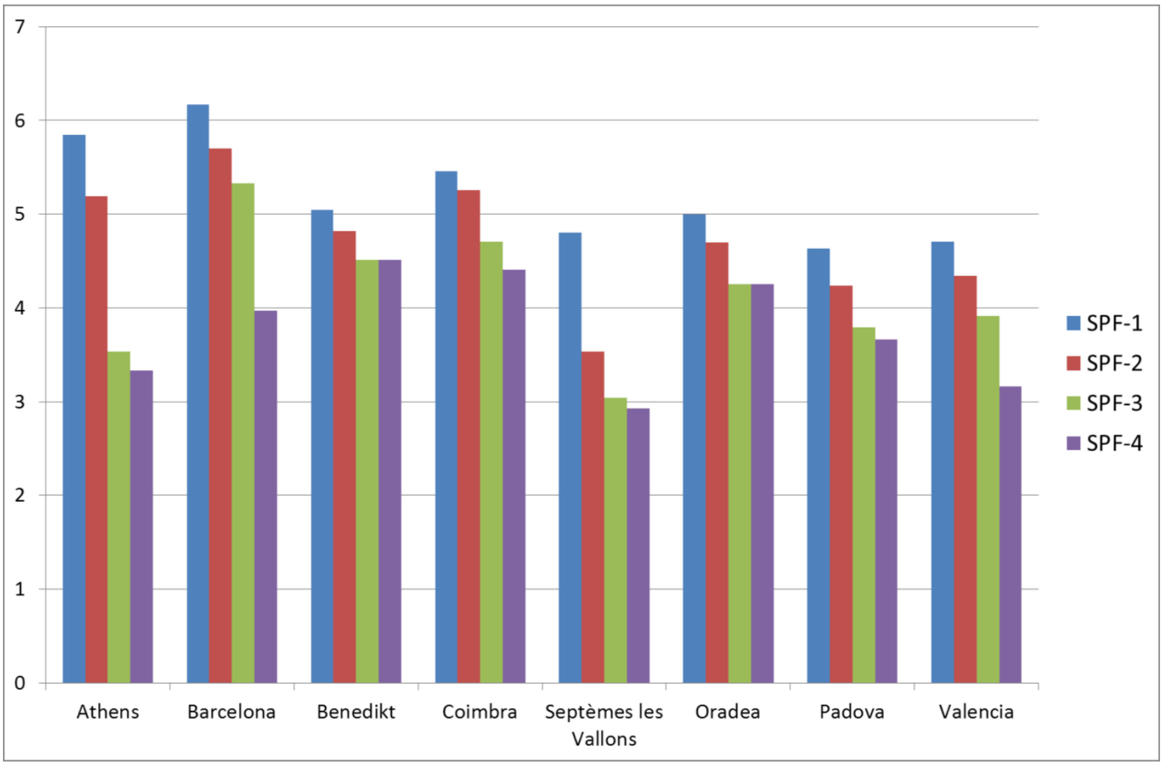

Figure 18: Seasonal performance factors in project demonstration systems calculated from monitoring data for heating during December 2013.

SPF4 includes all electricity consuming parts of a heating/cooling system, adding fan-coils and air handling units as well. COP4 and SPF4 measure the overall efficiency of the entire heating/cooling system and should be the objective of optimizing the system energy performance. We included fans in the calculation, as many heating systems and almost all cooling systems include fans. During the project, a new type of fan coil has been developed with 1/5 of the electricity consumption of fan coils available in the market. These fan-coils have been installed in Coimbra and partially in Valencia, resulting in SPF4 values very similar to SPF3 ones in those sites. Installation of such fan-coils in other demo sites as well, will further improve SPF4 values there. In Barcelona, SPF4 is maximized by synchronizing the air handling unit with the heat pump compressor, while at Septèmes-les-Vallons and Coimbra the applied algorithm results in further increasing SPF4. In Tribano (Padova) a different control algorithm has been applied which controls the frequencies of compressor, pumps and fans, which are all inverter driven, with the objective to maximize SPF4.

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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