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The European Project Ground-Med "Advanced Ground Source Heat Pump Systems for Heating and Cooling in Mediterranean Climate"

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ABSTRACT

The project Ground-Med, implemented by a consortium of 24 organizations from Europe and supported by the 7th framework program of the European Commission, concerns the development of the next generation of ground source heat pump systems, which will deliver heating and cooling to buildings with a measured year round seasonal performance factor SPF higher than 5. Technology development will include water source heat pumps of variable capacity, low electricity consumption fan-coil units, new heat/cool storage nodules, air handling units using condensing heat, pumps and fans of variable speed, advanced system control with temperature output depending on the heating/cooling load, as well as system design aiming at minimizing the temperature difference between the ground, the borehole heat exchanger, the heat pump, the heating/cooling water and the indoor temperature. These technologies will be demonstrated at 8 buildings of South Europe, and monitored for a period of more than 30 months. The project has duration of 5 years (2009-2013), and a budget of approximately 7.25 million Euros, with European financial support of around 60%.

1. INTRODUCTION

The Ground-Med project is a follow-up of the Groundhit – Ground Source Heat Pumps of High Technology European project, which resulted in the development of three water source heat pump prototypes of 15-20 kW capacity. The prototypes were developed by the French heat pump manufacturer CIAT, with the support of the Groundhit consortium.

The first prototype uses R410A as refrigerant and has energy efficiency in terms of COP (ratio of delivered heat over electricity consumption) improved by 20% compared to other heat pumps. The prototype with a COP of 6.2 achieves the class-A Eurovent specification for floor heating applications.

The second prototype was developed for the retrofit market and is able to operate with a high temperature heating system of 70-80°C supply and 50-60°C return temperatures with a COP around 3. For floor heating applications, the unit has a COP around 5.5 improved by 8% from other heat pumps.

The third prototype is able to utilize the heat content of warm groundwater in order to provide low temperature heating with the exceptional COP of 7 to 8, efficiency much higher that any other heat pump.

In Groundhit the focus was on the COP of the heat pump unit itself. Ground-Med moves one step further by focusing on the SPF of the whole system, including electricity consumption in the auxiliaries, which are the internal and external water circulating pumps, fan-coils, air handling units and heat storage nodules.

SPF is the average COP value integrated during the entire heating and cooling period of the year. COP corresponds to the efficiency of a heat pump when it operates at full load, but most of the time a heat pump operates at partial or reduced load; hence SPF is the parameter that should be used in the energy consumption calculations and a true measure of the energy performance of the system.

The target market now is the high efficiency market for heating and cooling in mild climate, which corresponds to low temperature heating systems coupled to a borehole heat exchanger exploiting the heat capacity of the earth at shallow depth 0-200 m and normal temperature 10-20°C.

2. GROUND-MED CONSORTIUM

24 European organizations form the Ground-Med consortium. It is coordinated by the Centre for Renewable Energy Sources and Saving of Greece, a non-profit research organization and the national coordination centre for renewable energy and energy saving which also coordinated Groundhit.

Three heat pump manufactures are involved in the project, namely CIAT - Compagnie Industrielle d'Applications Thermiques from France, Ochsner Wärmepumpen GmbH from Austria and Hiref Spa from Italy. For the heat pump technology development purposes they are assisted by the University of Oradea (Romania), the Institute of Systems and Robotics of the University of Coimbra (Portugal), the UPV - University Polytechnic of Valencia (Spain), The UCD - University College Dublin (Ireland), the UNIPD - University of Padova (Italy), the Technical University of Setubal (Portugal), the KTH - Royal Institute of Technology (Sweden), the CEA - Commissariat à l'Énergie Atomique (France) and the CRES - Centre for Renewable Energy Sources and Saving (Greece). The algorithms for integrated system control are developed by the University College Dublin with the support of the Institute of Systems and Robotics of the University of Coimbra, the University Polytechnic of Valencia and the consultants Besel S.A. from Spain.

Engineering design and construction of the demonstration heating and cooling systems where the developed technology will be integrated and demonstrated is performed by above organizations, together with the consulting enterprises on geothermal and renewable energy matters Gejzir Consulting (Slovenia), Ecoserveis (Spain), Groenholland (Netherlands), Eneren Srl (Italy) and the engineering works contractors Edrasis Ch. Psallidas SA (Greece).

Other organizations involved in the technology evaluation and dissemination and training activities of the project are the geothermal consultants GEOTEAM (Austria), the European Heat Pumps Association - EHPA, the European Geothermal Energy Council - EGEC, the European heat pumps testing, evaluation and certification centre of heat pumps CETIAT, the French industrial association for heat exchangers research GREThand the information centre FIZ – Fachinformationszentrum Karlsruhe GmbH (Germany).

3. TECHNOLOGY DEVELOPMENT

3.1 System Design

The aim is to achieve a seasonal performance SPF=5.0 for all year operation of the heat pump for both heating and cooling. This can be achieved by having a very efficient heat pump, which should be able to maintain its efficiency during low load operation. But this is not enough; the heat pumps should be allowed to operate under favorable temperature conditions, in terms of fluid temperature supplied by the BHE and in terms of temperature supplied to the indoor heating/cooling system.

In order to maximize operating efficiency, the ground source heat pump system should be able to operate with minimum temperature difference between its components, namely between the ground, the BHE fluid, the heat pump refrigerant in the external heat exchanger (evaporator-condenser), the refrigerant at the internal heat exchanger (condenser-evaporator), the water of the indoor heating-cooling system and the indoor air. For this reason, in Ground-Med demonstration buildings the water supply temperature to the indoor heating-cooling system will be set to 40°C during peak heating loads and 10°C during peak cooling loads.

In the countries of South Europe with Mediterranean climate, average surface ground temperatures are in the range 10-18°C and practically constant throughout the year below 5m depth. In addition, due to the prevailing geothermal gradient temperatures at 100m depth are 2-3°C higher (12-21°C) and at 200 m depth 5-6°C higher, e.g. 15-24°C. Therefore, a BHE supply temperature to the heat pump evaporator of 8°C is possible during peak heating loads. Our simulations using the Earth Energy Designed – EED simulator, showed that one way to achieve this is by drilling deeper BHEs (down to 250 m depth), 60% more BHE meters, using double-U rather than single-U configuration, thermally enhanced grout, and improved shank spacing for the BHE pipes. Another way is to drill 120% more BHE meters. Our simulations using the NIST/CYCLE_D heat pump cycle simulator showed that the corresponding improvement in COP is by 30% in heating mode and by 75% in cooling mode.

The comparison of the Ground-Med design to a typical design for a house in Athens is presented in Table 1. The simulated BHE temperatures after 10 years of operation are presented in figures 1 and 2 for typical BHE engineering design and in figures 3 and 4 for Ground-Med.

Table 1: GSHP design for heating-cooling a house in Athens

	Typical	Ground-Med
Heating capacity	10 kW	10 kW
Cooling capacity	8 kW	8 kW
Heating load	17.3 MWh	17.3 MWh
Cooling load	10.5 MWh	10.5 MWh
Soil type	Wet clay	Wet clay
BHE length	2 x 75m	1 x 240m
Type	Single-U	Double-U
Grout	Cement-bentonite-sand	Thermally enhanced
Spacers	none	yes
BHE fluid T min	-3.52 °C	7.98 °C
BHE fluid T max	42.8 °C	29.3 °C
Max BHE output, cooling mode	64 W/m	40 W/m
COP heating	3.95	5.16
COP cooling	3.57	6.30

As the heat pumps operates most of the time under low load conditions, in order to improve the seasonal performance factor, heat pumps of variable capacity will be considered, which should be able to at least maintain their efficiency at low load. Seasonal performance factors can be further improved by controlling the operating conditions of the heat pump.

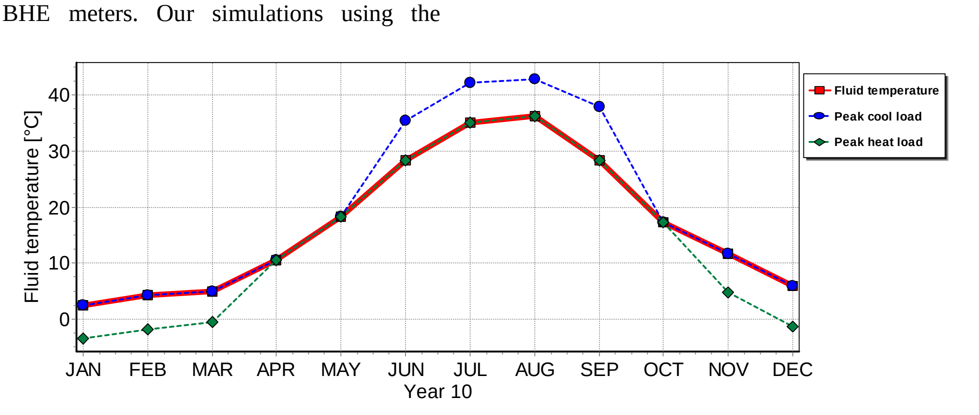

Figure 1: Temperature profile for BHE fluid during the 10th year of operation for typical engineering design.

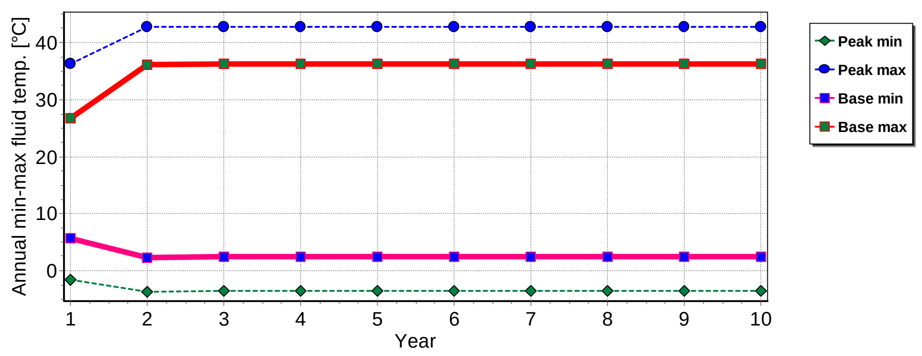

Figure 2: Evolution of BHE fluid temperatures for typical engineering design.

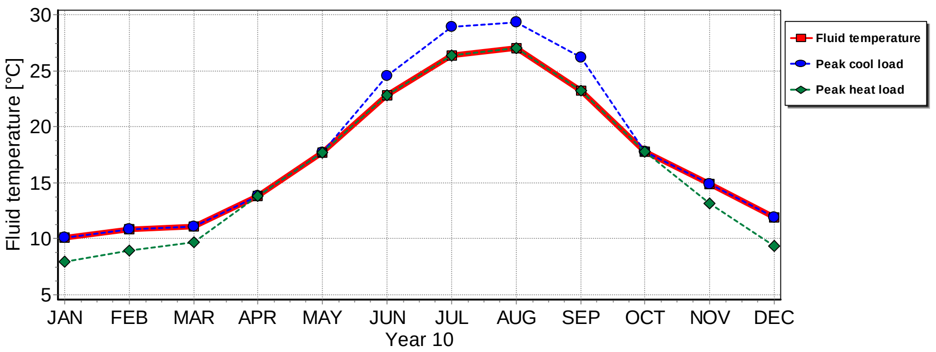

Figure 3: Temperature profile for BHE fluid during the 10th year of operation for Ground-Med.

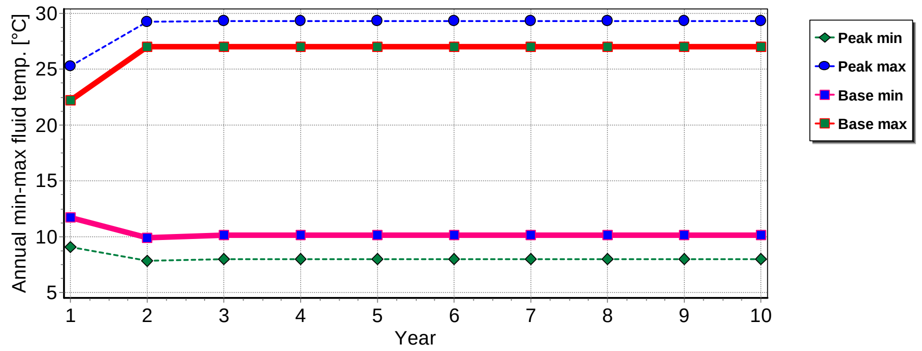

Figure 4: Evolution of BHE fluid temperatures for Ground-Med.

The BHE fluid supply temperature is self adjusted by the heat transfer mechanism within the earth, as can be observed in figures 1 to 4. This occurs due to the fact that the heat transfer rate is proportional to the temperature difference between the BHE and the temperature of the earth in the thermally unaffected region away from the BHE. Our simulations indicated that a BHE practically affects the earth temperatures in a radius of 1.5 m.

However, this is not the case for the building heating-cooling system, where a stable indoor temperature is desired. As the indoor system is sized for peak load and a given temperature difference between the heating-cooling water, in times of low load there is room to limit this temperature difference by relaxing the water temperature supplied by the heat pump, to levels improving its energy efficiency. One way to control this is by setting the heat pump supply temperature as a function of the ambient temperature and the desired indoor temperature.

Although the heat pump compressor is the system component with the highest electricity consumption, the electricity consumption in auxiliary components such as the water circulating pumps and the fan-coils can be also important, especially in times of low load. In order to limit this electricity consumption and improve the energy performance of the entire system, inverters regulating their flow rate should be installed in all such equipment, coupled to a central control system which will regulate all flows and temperatures according to the thermal load of the building.

Furthermore, Ground-Med project will include technology development of advanced fan-coils and air handling units with low power consumption, and improved comfort provision for the people using the building.

3.2 Heat pump Prototypes

Eight heat pump prototypes of capacities varying from 10 kW to 100 kW are under development. They will include scroll compressors of high isentropic efficiency coupled with high efficiency motors, electronic expansion valves for accurate evaporator's superheat regulation, oversized brazed plate heat exchangers as evaporators and condensers, high quality lubrication oil, electronic control able to interact with a building energy management system (BEMS), as well as some form of capacity regulation. Other components that lead to improved efficiency will also be considered. Contacts with compressors manufacturers will be established for this purpose.

The operating parameters of a Ground-Med prototype coupled to a BHE and a heating-cooling system are presented in figures 5 and 6 for heating and cooling modes respectively. The target COP for peak heating is 5.16 and for peak cooling 6.30. These COP values were calculated using the NIST/CYCLE_D heat pump cycle simulator, assuming compressor of 80% isentropic efficiency and 85% volumetric efficiency, motor of 95% efficiency coupled to inverter of 90% efficiency and very low temperature approach between the refrigerant and the water side in the evaporator and condenser. These COP levels are among the best possible that can be achieved by standard technology.

The first three prototypes are developed by CIAT and are an improved version of the first Groundhit prototype in terms of seasonal performance factor (SPF). They will have R410A as refrigerant. Variable capacity will also be considered.

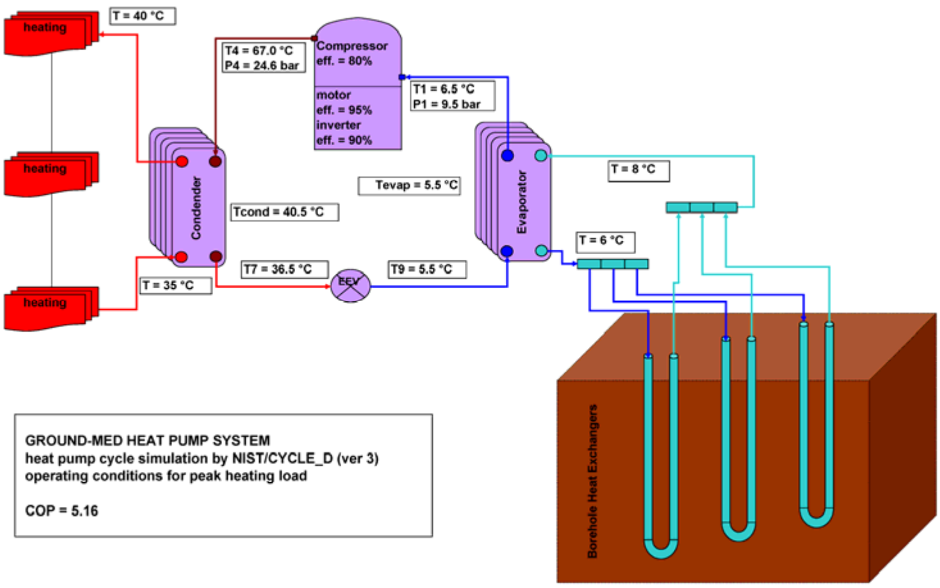

Figure 5: Ground-Med heat pump system operating parameters in peak heating load.

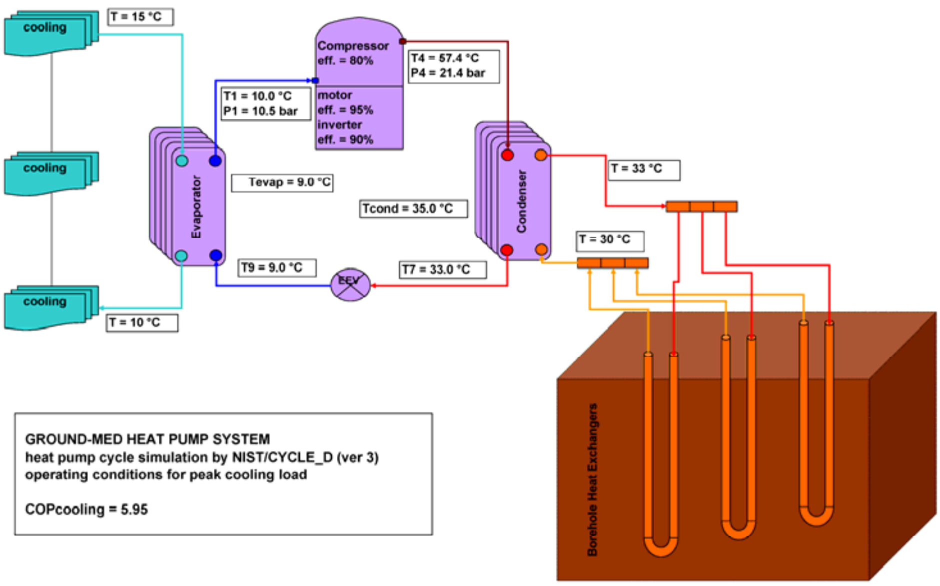

Figure 6: Ground-Med heat pump system operating parameters in peak cooling load.

The other three are developed by OCHSNER, using R407C as refrigerant. They are an improved version of their Golf Maxi and Standard series ranges, which already have COP of 5.7 for floor heating applications. Due to the high temperature glide of the R407C refrigerant, water circuit inversion during cooling mode operation is essential.

The last two are developed by HIREF using R410A as refrigerant and improving efficiency by redesigning the evaporator and associated refrigerant circuit parameters.

3.3 Other HVAC Components

According to the results of the GeoCool European project, Universidad Politécnica de Valencia (2006), the auxiliary components of a geothermal heat pump system such as circulating pumps and fan-coils may account for 30%-50% of the overall electricity consumption throughout both heating and cooling seasons, depending on the load of the system. For this reason it was decided to also consider such components in the technology development part of the Ground-Med project.

These are: advanced fan coil units of low electricity consumption, which will also be able to provide comfort heating when supplied by low temperature water, e.g. 35°C; an energy efficient air handling unit using condensing heat instead of electrical resistance for heating and de-humidification purposes; and a low temperature heat storage nodule.

The target reduction of electricity consumption in the advanced fan-coil units is 30%. This will be achieved by using a new type of permanent magnet brushless fan-coil motor, which has the highest performance in terms of energy efficiency, reliability, torque and weight. Its superior energy efficiency results from its low inertia, reduced friction and low electrical resistance. Its reliability results from the absence of brush dust, no electricity arching, and absence of items that tend to wear out such as commutator or brush. Further electricity consumption reduction can be achieved by low fan speed, which also results in improved comfort among people present in the room.

Air handling units condition the air entering a building to desired temperature and humidity levels. During summer, dehumidification is achieved by cooling the air to very low temperature so that its humidity is reduced to saturation levels for this temperature, and reheat it to the desired temperature levels. Reheating is usually done with an electrical resistor. The target of Ground-Med project is to develop an air handling unit of improved energy efficiency by replacing the resistor by a condensing coil and by introducing a variable speed motor for adjusting the air flow.

Heat or cold storage nodules are used in heat pump systems in order to store heat or cool during low load periods in order to use it during extreme conditions, e.g. peak or very low load. This allows a smoother operation of the heat pump and increased operation in full capacity, fact that reduces the seasonal electricity consumption in auxiliary components. It also allows reduced sizing for the heat pump and BHE, hence in lower system capital costs. In addition, heat/cold storage nodules can be used in order to allow operation of the heat pump only during hours of reduced electricity tariffs, further improving the financial performance of the system.

They include a phase change material with melting point at a given temperature, the most well known of which is ice for cols storage. Ground-Med project will evaluate the feasibility of this technology and develop new nodules of optimal temperature for maximum energy efficiency of a heat pump system.

3.4 System Controls

The primary target of the Ground-Med system controls is be able to regulate the water supply temperature to the building's heating-cooling system according to the corresponding energy load. This will allow heating with the lowest possible water temperature during winter and cooling with the highest possible temperature during summer, achieving maximum possible energy efficiency in each demonstration site. This is illustrated in figures 7 and 8, which presents the target COP of the Ground-Med heat pumps as a function of water supply temperature to the building heating-cooling system.

The temperature of the heat pump water supply to the building will be regulated between 40°C during peak load and 30°C during minimum load. The corresponding temperature range while cooling during summer will be 10-20°C.

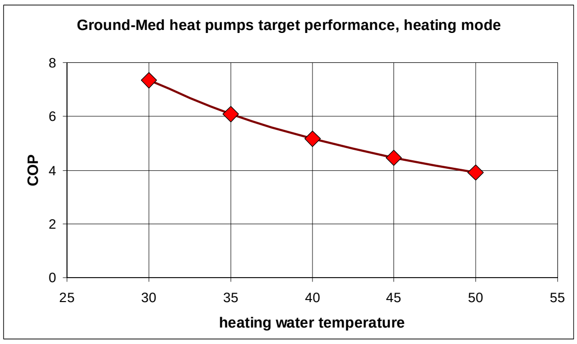

Figure 7: Ground-Med heating mode; heat pump efficiency target as a function of the water supply temperature.

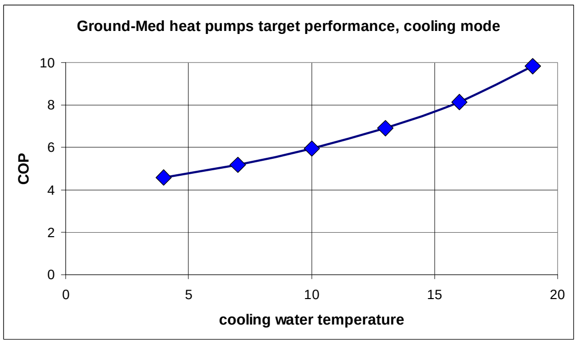

Figure 8: Ground-Med cooling mode; heat pump efficiency target as a function of the water supply temperature.

A second objective is to control the heat pump, the BHE and water distribution pumps, the fan-coils and the air handling units, in order to minimize electricity use, especially at times of low load. Special control strategies and algorithms regulating heat pump capacity, circulation pump flow, set-point temperature, energy efficiency, energy storage, etc. will be developed for this purpose. Prior development of a mathematical model simulating the heat pump system and the building performance is essential. These algorithms will be incorporated into an advanced microprocessor control board, which will cooperate smoothly with the building energy management system and provide data collection as well.

Another objective is to allow remote monitoring of all parameters through the Internet; a data management system will be developed for this purpose.

4. DEMONSTRATION AND MONITORING

The Ground-Med technology will be demonstrated and monitored at the demo buildings of South Europe presented below. Their location is shown in figure 9.

CIAT subsidiary offices/workshop in Septemes les Vallons: the building, which is located near Marseille at the South of France, comprises 330 m² of offices and workshop, and has heating/cooling needs of 50 kW. There, one Ground-Med water source heat pump will be coupled to a borehole heat exchanger and to an indoor system of Ground-Med fan-coils, air-handling unit and heat storage nodules.

University of Oradea (UOR) T-Building: It comprises 3 floors of workshops, labs and classrooms of ~3000 m² total. It was built in 1970 and is under renovation. The new heating/cooling system will comprise pipes embedded in the side walls, supplied by a Ground-Med heat pump coupled to a BHE. Heating, cooling needs of the renovated building will be 80 kW and 40 kW respectively.

University of Coimbra building: it comprises 2100 m² of offices, classrooms, labs and a conference room. A Ground-Med heat pump of 100 kW coupled to a BHE will provide heating/cooling to 1500 m² of the building.

Benedikt Municipal Hall: located 120 km NEE of Ljubljana, it comprises a main hall, two meeting rooms and several auxiliary spaces in two floors of 320 m² total surface. Heating /cooling needs amount at 24 kW and 10 kW respectively. A Ground-Med heat pump coupled to a BHE will replace the existing diesel boiler, using existing radiators and an additional air handling unit.

University Poly of Valencia offices: A 20 kW Ground-Med heat pump will be installed in parallel to an existing propane ground source heat pump in order to provide heating and cooling to 250 m² of University staff offices.

Barcelona Sun-Factory: La Fabrica del Sol is the last standing building of the old gas plant, now owned by the Barcelona City Council and renovated as a demonstration building for renewable heating, cooling and electricity. An 80 kW Ground-Med heat pump coupled to a BHE will serve the two floors of 1000 m² of indoor space.

HIREF factory and offices: A 8.5 kW Ground-Med heat pump coupled to a borehole heat exchanger and fan coil units, will provide heating and cooling to 4 rooms of total 150 m² surface.

Edrasis-Psallidas headquarters: A Ground-Med heat pump of 55 kW coupled to a BHE, will cover part of the heating /cooling needs of the two floors of 2000 m², which is now heated by a diesel oil boiler and cooled by air source chillers, feeding 14 air handling units and 88 fan coils. The building energy management system will give priority to the Ground-Med heat pumps in order to achieve maximum efficiency.

The design operating temperatures of the indoor heating /cooling system and the borehole heat exchanger for each demo building are presented in Table 2. These temperatures allow operation of the heat pumps with optimum COP.

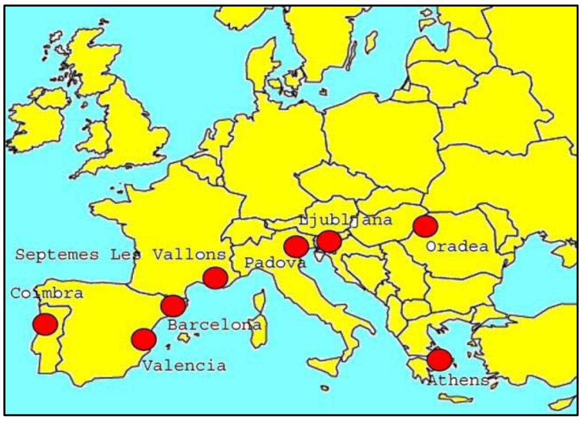

Figure 9: Ground-Med demonstration sites.

After the demonstration systems are constructed they will be monitored under real operating conditions, by recording useful heat/cool delivered to the building, heat drawn from or sent to the ground, electricity consumption to the heat pump compressor, all pumps and fans, and other parameters. The aim will be to evaluate the Ground-Med heat pump systems in terms of energy performance (SPF), reliability and acceptability by the users, as well as to fine tune the control algorithms developed for the project. All data will be available on line through the Internet.

Table 2: Design temperatures of Ground-Med demo systems

Site	Water to the building		Water from the BHE	
	heating	cooling	heating	cooling
Ciat	40°C	10°C	10°C	30°C
Oradea	35°C	15°C	8°C	25°C
Coimbra	40°C	10°C	10°C	30°C
Benedikt	45°C	18°C	8°C	25°C
Valencia	40°C	10°C	15°C	26°C
Barcelona	40°C	10°C	10°C	30°C
Hiref	40°C	10°C	8°C	30°C
Edrasis	40°C	10°C	10°C	30°C

5. PROJECT MANAGEMENT

The work is broken down to 9 work packages as shown in table 3. One member of the project consortium has been appointed as responsible for each work package.

Ground-Med project started on 1 January 2009 with the technology development tasks of work packages 2, 3 and 4, and the demonstration systems engineering design of work package 5, all which are expected to be completed by the end of October 2010. All construction activities are planned to be completed by June 2011, when monitoring and technology evaluation tasks will commence. The project results will be available at the project web site http://www.groundmed.eu/; they will also be disseminated during the two workshops and the 7 seminars which will be organized for this purpose; other scientific publications and announcements will be also made. The project will end on 31 December 2013.

Table 3: Work breakdown in work packages (WP)

WP	Activities summary	Leader
1	Project management	CRES
2	Technology development of large capacity advanced heat pump prototypes and system components	CIAT
3	Technology development of low/medium capacity advanced heat pump prototypes	UNIPD
4	Development of integrated system control	UCD
5	Integrated system design	UPV
6	Construction of demonstration systems	EDRASIS
7	Operation, monitoring and fine tuning	CRES
8	Technology evaluation	CETIAT
9	Dissemination and training	FIZ

Ground-Med budget amounts at approximately 7.25 million Euros, ~60% co-financed by the European Commission through the seventh framework program, theme-5 on energy. It is classified as a collaborative project with Grant Agreement (contract) number 218895.

CONCLUSION

Ground-Med project will effectively demonstrate the next generation of geothermal heat pump systems in 8 buildings of South Europe, which will serve as an exemplar for future heating and cooling systems in terms of engineering design (borehole heat exchanger, indoor heating-cooling system, water supply temperature range) and selection of components (heat pump, pumps, fan-coils, system control, air handling units and heat storage nodules) for minimal energy requirements.

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