GROUND-MED PROJECT AT THE UNIVERSITY OF ORADEA

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Abstract: The paper presents an overview on ground source heat pumps technology, focusing then on Ground-Med project, describing its aim and objectives, partners involved, location of demo-sites and heat pump manufacturers. Then, the article presents the University of Oradea demo-site, showing the chosen building, describing its thermal characteristics and the technical solution which is used for space conditioning.

Key words: Ground coupled heat pump, Ground-Med project demo-site

1. INTRODUCTION

Ground source heat pumps (GSHP) are systems comprising:
a) ground heat exchanger (pipes buried horizontally in trenches or vertically in boreholes, through which water is circulated as a heat carrier),
b) water source heat pump,
c) low temperature heating (and cooling) system (fan-coils, slim pipes under the floor or on the walls, etc.).

As they exploit the favorable heat transfer properties of water and the mild ground temperature, which remains almost constant throughout the year, independently of external weather conditions, ground source heat pumps provide efficient heating, cooling and domestic hot water supply to the buildings. In cooling mode, they use 30% less electricity than air source heat pumps of latest technology. In heating mode, currently available technology provides a seasonal performance factor (SPF) up to 4, which means that out of 4 units of thermal energy delivered, 3 units are free geothermal energy and only 1 unit is electric energy consumed by the heat pump, resulting in a 75% energy savings.

As regarding primary energy, the scheme below illustrates how 1 unit of fuel energy is transformed to 2.36 units of useful heat by ground source heat pumps (Figure 1), indicating that GSHP can play a major role to rational use of energy and fighting climate change. This is being recognized more and more by European citizens, who adopt the technology in increasing numbers.

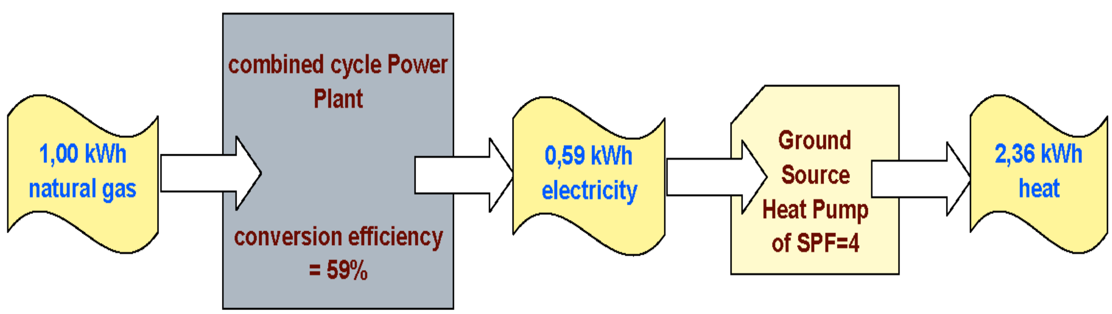


Fig. 1 - Primary energy converted to useful heat by GSHP

As they are a reliable and environmental friendly technology, they can be an effective aid to fulfill the targets for renewable energy use and CO_2 emissions reduction.

Geothermal energy is becoming all around Europe one of the most interesting sources of renewable energy for the future in the sense of heating and cooling by ground coupled heat pumps. Energy policy and climate protection are top issues as each head of state and government committed to a binding target for 20% renewables by 2020. However, although ground source heat pump technology and market are developed in Western European countries, the corresponding market in Romania is at early developing stage, despite the fact that both economics and CO_2 emissions reduction potential are favorable, due to prevailing climatic conditions and the need for cooling.

The cooperation work program for Energy supports technology development and demonstration of ground source heat pumps aiming at increasing the coefficient of performance (COP) of the heat pump and of the overall system in order to reduce the electricity consumption and extend its use in Europe.

The increase of efficiency will reduce operating costs and pay-back time. GROUND-MED is a collaborative project which demonstrates innovative ground source heat pump solutions in 8 buildings in Mediterranean EU member States. It involves 25% research and technology development and 75% demonstration (including dissemination activities) of integrated GSHP systems for heating and cooling of considerably higher seasonal coefficient of performance (SPF) than present technology.

2. GROUND-MED PROJECT

2.1. Project objectives

The main objective of GROUND-MED is to demonstrate the superior energy efficiency (SPF>5.0 for year round operation) of the next generation of ground source heat pump systems for heating and cooling in South Europe. For this purpose 8 building-demonstration sites have been selected (one in Portugal, two in Spain, one in South France, one in Italy, one in Slovenia, one in Romania and one in Greece).

The global aim is to demonstrate integrated ground source heat pump systems of:

- annual SPF for both heating and cooling higher than 5.0
- less than 7 years payback time compared to a system comprising natural gas boiler of 0.04 €/kWh for heating and air source heat pumps of COP = 3.5 for cooling
- high system durability expressed as at least 20 years life span.

The first statement has a straightforward direct impact on energy efficiency. The other two statements define whether the proposed technological solutions and practices will be widely accepted by the end users or not, and are essential conditions, if we aim at their wide market penetration and large scale impact.

Demonstrating the superior performance of the technology is essential in order to facilitate its introduction on the market.

In order to demonstrate ground source heat pump systems of measured SPF>5, which is an ambitious target, the following technological solutions or practices will be demonstrated and evaluated:

- *Improve the energy efficiency of the heat pump units during all year operation*: for this purpose the next generation of heat pumps will be developed by further optimizing individual components and introducing energy efficiency improving technologies such as variable capacity compressors. In addition, collaboration will be established by the consortium with compressor manufacturers towards the development of new compressor technology matching high efficiency motors with superior isentropic efficiency. In particular, develop water source heat pumps of SPF>5 in both heating and cooling modes for operation with a ground heat exchanger (8°C water supply to the evaporator in winter and 25-30°C water supply to the condenser during summer) and produce 8 prototypes for all demo sites as follows: 3 prototypes of large capacity, 3 prototypes of medium capacity and 2 prototypes of small capacity one of which will use natural fluids as refrigerant.
- *Reduce electricity consumption of key system components* as follows:
  – Develop low energy fan-coil units for operation with water of low temperature (35°C) in heating mode; produce prototypes for 50-100 kW system.
  – Develop air handling units (AHUs) using condensing heat rather than electric resistors for heating the air during winter and removing humidity during summer; produce one prototype.
- *Reduce the capacity of the heat pump and the size of the ground heat exchanger*, while improving the COP and reliability of the system by using cold and heat storage. For this purpose prototype nodules for low temperature heat storage (~40°C) will be developed, and the feasibility of the technology will be evaluated.
- *Develop system controls*, in order to minimize the temperature difference the heat pump has to overcome in order to heat or cool the building which results in large improvement of system SPF. This can be achieved by:
  - Control the water temperature delivered by the ground heat exchanger according to the heating/cooling load.
  - Control the water supply temperature to the heating/cooling system according to the heating/cooling load, e.g. in heating operation the water supply temperature from the heat pump could be 40°C at peak load and only 30° at partial load, while during cooling operation it could vary from 8°C at peak load and 15°C at partial load.
- *Optimize the ground heat exchanger in terms of improving the overall system SPF, while keeping capital costs at acceptable levels*. For this purpose, ground heat exchangers will be designed using water (no antifreeze) as circulating fluid and at least 8°C water supply to the evaporator in winter and 25-30°C water supply to the condenser during summer.
- *Optimize the water temperature the heat pump supplies to the heating/cooling system of the building*, e.g. as low as possible temperature during heating and as high as possible temperature during cooling mode.
- *Design each demonstration heating/cooling system for maximum energy efficiency*.
- *Integrate the automation of the heat pump*, the pumps, and fans with the building energy management system and optimizing overall energy performance.
- *Develop a regular maintenance program for improving system reliability* by developing standard operation and maintenance specifications and procedures for each system.

2.2 Consortium members

The GROUND-MED consortium comprises 24 organizations, mainly from South Europe, but with participants from central and north EU member States as well. It includes a wide diversity of GSHP actors, such as major research and educational institutes (CRES, CEA, UOR, ISR, UPV, UCD, UNIPD, ESTSetubal, KTH), leading heat pump manufacturers (CIAT, HIREF, OCHSNER), the national and European industrial associations concerning heat pumps and geothermal energy (EHPA, EGEC, GRETh), leading consulting organizations in geothermal or renewable energy matters (GEJZIR, ECOSERVEIS, GROENH), specialized works contractors (GEOTEAM, EDRASIS), the European heat pumps testing, evaluation and certification centre of heat pumps (CETIAT) and a well known information centre (FIZ).

The 8 demonstration sites are dispersed in a wide geographic area (Portugal, Spain, South France, Italy, Slovenia, Romania and Greece), in order to maximize project market impact.

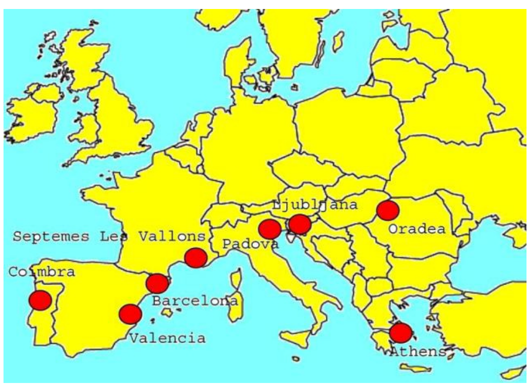


Fig. 2 - GROUND-MED demo-site locations

For each one of the 8 demonstration sites, one partner, usually the building owner (CIAT, HIREF, UOR, ISR, UPV, EDRASIS) or having established partnership relation to the building owner (GEJZIR, ECOSERVEIS), has been appointed as responsible partner.

In order to exploit the experience gained and research results from previous European projects GROUNDHIT (heat pump technology development and demonstration) and SHERPHA (heat pump technology development using natural refrigerants) the consortium includes 6 organizations involved in the GROUNDHIT project (CRES, CIAT, UOR, GEOTEAM, EGEC, ESTSetubal) plus 10 organizations from the SHERPHA project (EHPA, FIZ, HIREF, UPV, GRETh, UCD, UNIPD, CETIAT, GROENH and KTH).

The Centre for Renewable Energy Sources and Savings - CRES, GROUND-MED coordinator, is an experienced coordinator of European projects and as the national coordination centre of Greece for renewable energy sources and energy saving has been actively involved in the coordination of many European and national technology development and demonstration projects on ground source heat pumps.

The heat pump manufacturers involved in technology development tasks of GROUNDMED are CIAT, the manufacturer of the GROUNDHIT prototypes, HIREF, manufacturer of SHERPHA natural fluid prototypes and OCHSNER as a heat pump manufacturer of central Europe where the corresponding technology is well developed, and in particular of Austria, where GSHPs have a leading market position.

3. INNOVATIVE TECHNIQUES

Until now, heat pump research activities focused on COP improvements. GROUND-MED will advance the technology one step further from GROUNDHIT prototypes of COP>5.5 at nominal conditions by focusing on SPF. For this purpose, and considering that ground source heat pumps operate most of the time at much different conditions than the nominal ones, apart from improving heat pump units in terms of COP, technologies resulting in higher SPF will be considered.

Present ground source heat pumps have ON-OFF modulation and are usually designed for use with fan-coils at 40/45°C, or 50°C condensing temperature, which is the set point for covering heating peak loads. This means that the COP of the heat pump will be 3.5 in all conditions, and the corresponding SPF somewhat lower due to high starting current, electricity consumption during stand-by periods and auxiliary power consumed by the water circulating pumps, the fan-coils and the air handling units.

In many cases however, radiators are used instead of fan-coils, which results in even higher condensing temperatures and even lower efficiency.

The heat pumps developed for the GROUND-MED project will be able to modulate the condensing temperature according to the heating load requirements, so that their COP will be maintained above 5.0 most of the time. Furthermore, the set point that corresponds to maximum heat load, will be reduced to less than 40°C, by developing a specially designed fan-coil that can operate at low temperature with 30% less electricity consumption (present fan coils are designed for temperatures higher than 45°C and their operation at lower temperatures is costly in terms of electricity consumption).

The operation of the heat pump in cooling mode during summer will be improved accordingly, by setting the heat pump for operation delivering cold water between 15/10°C and 25/20°C, compared with 12/7°C of present systems.

Furthermore, the operating conditions within the borehole heat exchanger (water flow rate and temperature range) will be optimized based on the above concept, aiming in maximizing the overall system SPF, defined as the useful heat and cold delivered by the GSHP over the sum of electricity consumption at the heat pump, the water pumps, the fans of the fan-coils, and the air handling unit.

In order to obtain operation at the above discussed conditions, innovative ground source heat pump systems will be developed and demonstrated integrating the following technologies / solutions:

- Advanced water source heat pumps of high efficiency:
  - ✓ Capacity modulation
  - ✓ New generation of compressors matching motors of high efficiency with superior isentropic efficiency
  - ✓ Innovative heat exchangers for high efficient cooling as well as heating
  - ✓ Use of natural refrigerants in one prototype
- Innovative system controls integrating all components (BHE pump, heat pump, water distribution pump, fans);
- Smooth system start-up;
- Advanced fan-coils:
  - ✓ low temperature operation in heating mode,
  - ✓ innovative fan-coil motor, brushless type (a brushless permanent magnet motor is the highest performing motor in terms of torque vs. weight, efficiency and reliability. Some of its outstanding features are:
    - • Very high torque to inertia ratio (on interior rotors only)
    - • Zero out-gassing (no brush dust)
    - • Very high peak torque (on interior rotors)
    - • No arcing (use in explosive environments)
    - • Very high reliability (no commutator or brush to wear out)
    - • Potentially higher efficiency (due to no brush friction, lower electricity resistance)
- Advanced air handling units utilizing condensing power for heating and humidity control
- Innovative integrated system design:
  - ✓ minimizing temperature difference between the BHE and the building heating/cooling system
  - ✓ operation at variable temperature to match the heating/cooling load.

4. UNIVERSITY OF ORADEA DEMO-SITE

4.1 Building description

One demonstration site of the GROUND-MED project is located at the University of Oradea. The City of Oradea is located in the western part of Romania, close to the border with Hungary, is the capital city of the Bihor County, and has a population of about 200,000. The University of Oradea campus is located in the southern part of Oradea. The climate in Oradea is basically mild temperate continental with some Mediterranean influence, characterized by cold winters and hot summers.

At an initial phase of the project, building T on the main university campus was selected as demo-site. It comprises seminar rooms, laboratories, offices, and a workshop, displayed on 3 levels and having a total area of 2600 m^2. After calculating the building heat losses we discovered they are too large to be covered by a medium size heat pump (up to 80 kW) as required by GROUND-MED project. We discussed the possibility of taking some measures in order to reduce the heat losses (minimum 10 cm of polystyrene on external walls, changing the single glazed metallic frame windows with double glazed in plastic frames), but the university administrative management disagreed. Instead, they offered another building, having a smaller heat demand, and we decided to install the demonstrative system there.

The building used to be the university library, but as the University of Oradea developed very much during the last 20 years, it is now too small for this purpose and a new building was constructed for the library. Due to its age and very high heat losses (mainly through the windows) the building was planned for complete renovation starting in 2010. As the building was declared architectural heritage any rehabilitation project needs a special approval from the relevant authorities, which usually takes a long time. The building suited very well the GROUND-MED project from technical point of view, but not from the commissioning timing and monitoring period point of view. Therefore, in spite of the fact that we had made all the calculations for heat/cold demand, simulations of ground heat exchange and detailed design of the heating circuit, we had to change the building again.

Finally, a newly refurbished building, belonging to Faculty of Arts, Department of Visual Arts, was offered by the university management and accepted, as it fulfilled all requirements (Figure 3). The location of the three buildings (T,J and Faculty of Arts) is indicated in Figure 4.

Fig. 3 - Demo-site building - main facade

The building, which is entirely conditioned by the ground source heat pump, has been retrofitted in 2010. It has a total usable surface area of 753 m^2, equally divided between the two stories (ground floor and first floor). The building has 19 rooms, 2 restrooms and a stair case. Six of the rooms are offices, one is computer laboratory, eleven are seminar and laboratory rooms for art works (paintings, sculptures, decorative designs etc.) and one is the technical room (where the heat pump is now installed).

The exterior walls of the building are made of compact red brick, 0.5 m thick, with outside thermal insulation 0.08 m thick polystyrene, with a total thermal resistance 2.668 $m^2 \cdot K/W$. The windows are of 3 different sizes, all double glazed with plastic frames, with a thermal resistance of 0.5 $m^2 \cdot K/W$.

The floor of the ground level: 0.05 m gravel, 0.1 m reinforced concrete, 0.05 m polystyrene, 0.05 m cement plaster, thermal resistance 1.382 $m^2 \cdot K/W$.

The floor of the first level: 0.12 m reinforced concrete, 0.03 m polystyrene, 0.05 m plaster, thermal resistance 0.884 $m^2 \cdot K/W$.

The first level ceiling: 0.12 m reinforced concrete, 0.15 m rock wool, thermal resistance 3.831 $m^2 \cdot K/W$ (plus thermal insulation under the roof tiles).

Fig. 4 - Location of Buildings J, T and Visual Arts

4.2. Building thermal load

To be able to chose a heat pump that can provide heating/cooling of a certain building, its maximum heat losses and gains must be calculated.

In Romania, the standard procedure to determine a building load is to assume a "worst case scenario" in which a minimum outdoor temperature is given for each location. For instance, a -15°C temperature is set for Oradea area. The calculations are made for each room separately according to SR 1907/97. Figure 5 shows the ground floor plan, and Table 1 the nominal thermal power of each room.

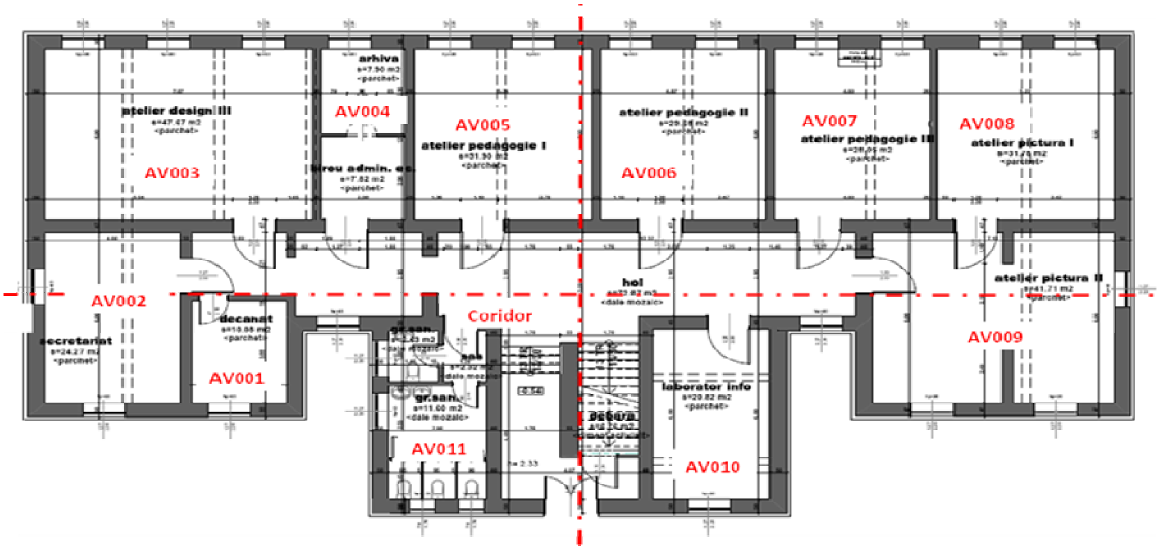


Fig. 5 - Geometrical characteristics of the ground floor of Visual Arts building

Table 1: Thermal loads of each room

Room No.	Thermal Load [W]	Room No.	Thermal Load [W]
P01	957	E01	982
P02	1976	E02	2033
P03	3351	E03	4549
P04	974	E04	1873
P05	2018	E05	3520
P06	1911	E06	2634
P07	1826	E07	3074
P08	2329	E08	1645
P09	3273	E09	1839
P10	1596	E10	1887
P11	1903	Total	24036
P12	1549		
Total	23663		

The standard indoor design temperature is 20°C. The thermal power demand for a constant indoor temperature is a function of the outdoor air temperature and the wind velocity.

In order to determine the real building load, in a dynamic behavior, it is necessary to know the daily temperature variation over the year (Figure 6). It may be seen that for one day there are 3 temperature values: the minimum temperature, the maximum temperature, and the average temperature, all of them being calculated as a multi-annual mean over more than a 100 years. From the graph below, it is obvious that the lowest mean temperature over 24 hours never exceeded -10°C. Occasionally, lower temperature might be reached, but for a shorter period of time (in terms of minutes or hours), therefore a design outdoor air temperature of -7°C is recommended. It is neither economic, nor necessary to design the heating system for the minimum measured outdoor temperature because the heat stored in walls, floor, ceiling, furniture etc. tends to level off the indoor temperature variation for short periods of time (up to three days) as demonstrated by Karlsson in [1].

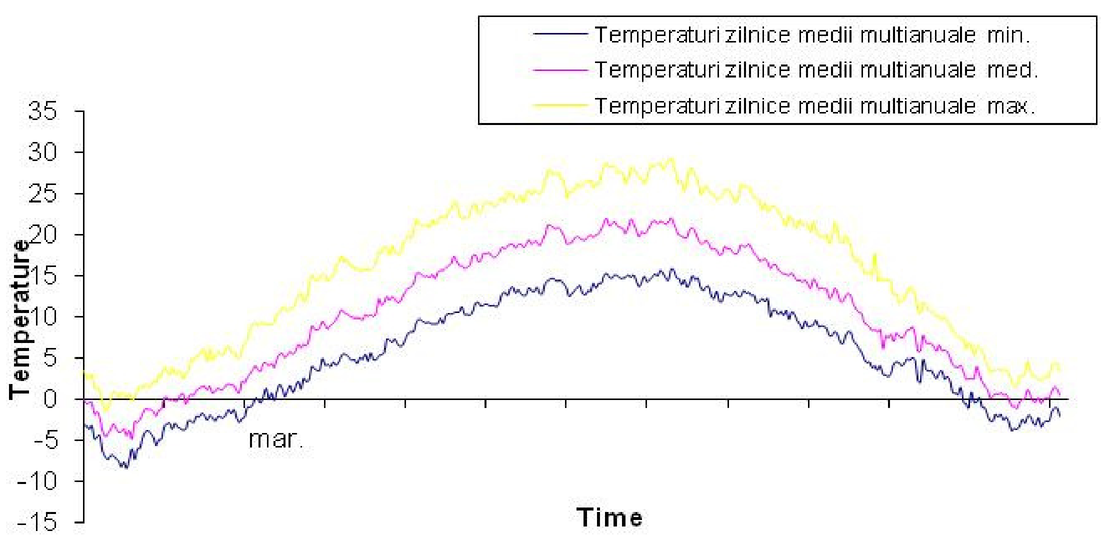


Fig. 6 - Multiannual daily mean temperature for Oradea area

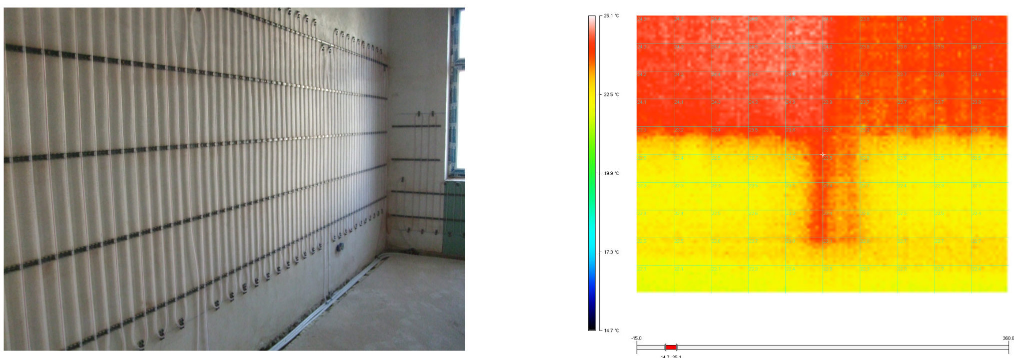
Based on these meteorological data, the monthly energy consumption of the building is presented in Table 2.

Table 2: Monthly thermal energy consumption of the building

Month	Energy consumption [MWh]
January	8090.16
February	6368.85
March	5387.70
April	3201.64
May	1566.39
June	344.26
July	0
August	0
September	1428.69
October	3494.26
November	5009.02
December	7246.72
	42137.71

4.3 Heating system of the building

The heating/cooling system of the building consists of radiant walls, PE pipes of 9.9 mm internal diameter and 1.1 mm wall thickness being placed on the walls at 8 cm spacing (Figure 7a), and covered with a special plaster.
The flow is distributed to two sets of manifolds on each floor, each of them supplying about the same number of rooms. Based on the results presented in Table 1, the length of each circuit was calculated. Since it can't exceed 60 m because of too high pressure losses, some of the rooms, having a large thermal load, will need several circuits. Figure 7b) shows the flow/return pipes of two circuits captured using a thermography camera.
Each room has a temperature sensor which communicates by radio with a control valve on the supply pipe on the manifold.
The corridors and restrooms on each floor are conditioned by 4 ceiling mounted fan coil units (one on each corridor, and one in each restroom).



a) b)

Fig. 7 - Heating/cooling wall pipes

4.4. Heat Pump System

The heat pump is a prototype (Figure 8) manufactured by OCHSNER Wärmepumpen GmbH (Austria). It is internally reversible and supplies heating and active cooling (no hot tap water). The heat pump also controls four 3-way valves to change the flow direction on the outdoor and indoor circuits.
The nominal heating capacity is 37.3 kW and the nominal cooling capacity is 31.1 kW. According to the lab tests performed by the manufacturer in certain operating conditions, the heating capacity is 36.66 kW, the compressor's electric power consumption is 6.5 kW, and the calculated COP is 5.64 (10% increase).
Both the condenser and vaporizer are flat plate made of stainless steel 1.4401. The compressor is Scroll (full hermetic). The working fluid is R 407C.

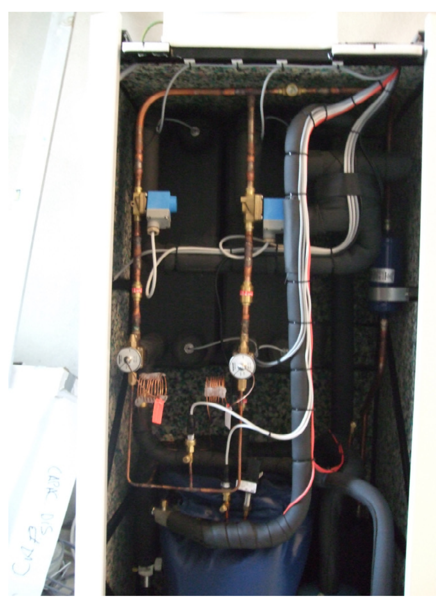


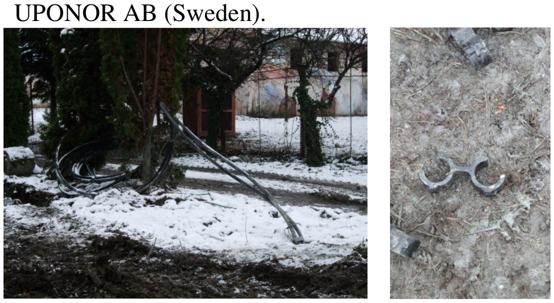
Fig. 8 – Heat pump prototype

4.5. Geothermal System

Since a ground source heat pump system consists of three major components: the building heating/cooling system, the heat pump system, and the underground system, the last one is on focus now.

First, we have to set the type of borehole heat exchanger, and consequently, to determine the length and number of boreholes, according to the building load, the heat pump heating capacity and COP.

The borehole heat exchangers are single-U type with a shank spacing of 75 mm (spacers placed every 2.5 m), made of HDPE, the nominal diameter is 40 mm, with 2.4 mm wall thickness (Figure 9). The borehole heat exchangers are manufactured by UPONOR AB (Sweden).



a) b)

Fig. 9 – Borehole heat exchanger geometry

The selected borehole configuration (Figure 10) is due to the available space for drilling. The ground coupled system consists of 10 boreholes arranged in a rectangular grid (two lines of 5 boreholes each). The distance between adjacent boreholes is 10 meters. Each borehole has 130 m depth and 150 mm diameter.

The grouting material is coarse sand from bottom to 10 m below surface, and bentonite for the upper 10 m to prevent the infiltration of warm water from a near-by thermal river to infiltrate in the boreholes, for allowing free cooling during low partial loads.

The manifolds are located in a concrete cellar placed in the middle of the borehole field, and are connected to the heat pump by a supply and a return pipe placed 2 m below surface, same as the connections to the borehole heat exchangers.

The fluid in the outdoor loop is de-mineralized water with 10% mono-ethylene glycol to avoid freezing, as the system was started in heating mode in winter, with the indoor walls still wet. It is intended to replace the anti-freeze with plain water in the future, if measurements will show no freezing danger.

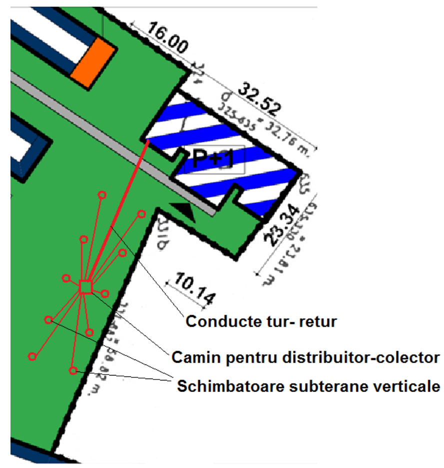


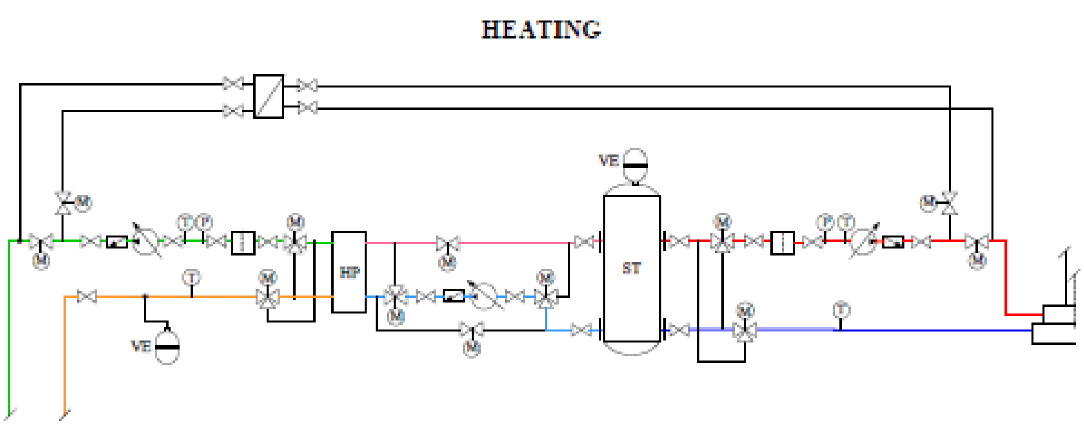
Fig. 10 – Borehole configuration: 2 x 5 rectangle

4.6. Hydraulic layout system

The hydraulic layout for each type of operation (heating/active cooling/passive cooling) is shown in Figure 11. For passive cooling, a plate heat exchanger is needed, as the indoor circuit is filled with plain water, while the outdoor circuit is filled with a mixture of de-mineralized water with 10% mono-ethylene glycol.

For heating and active cooling, a 1,000 l storage tank is placed between the heat pump and the indoor loop. A 7 kW electric resistance in the storage tank can be used for peak loads (and partial back-up).

Since there are three major circuits, the hydraulic layout presents three circulation pumps, one for the geothermal circuit, one for the building circuit, and one between the heat pump and storage tank.



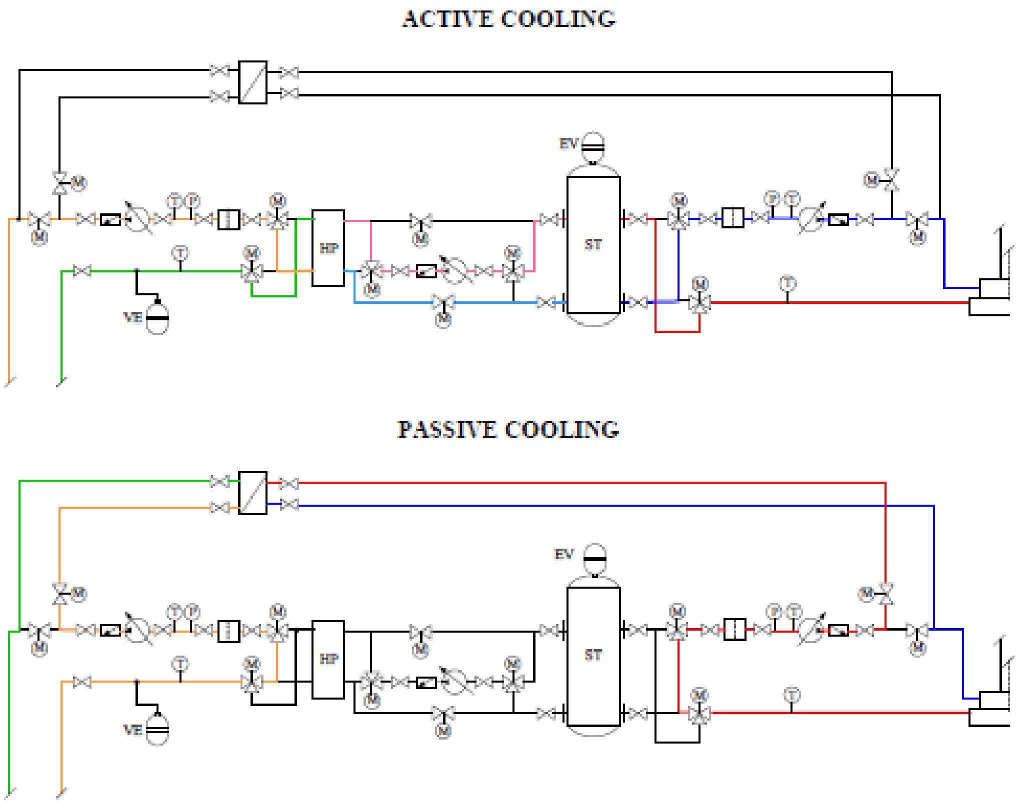


Fig. 11 – The hydraulic layout out of Ground-Med Oradea demo-site

All the equipment mentioned in Figure 11 may be seen as built in Figure 12.

Fig. 12 – The technical room

4.7 Data acquisition and monitoring system

The following parameters will be monitored by this system: external temperature, internal temperature, heat pump power consumption, external circulation pump power consumption, internal circulation pump power consumption, fan coil power consumption, internal circulation water flow, external circulation water flow, condenser inlet temperature, condenser outlet temperature, evaporator inlet temperature, evaporator outlet temperature.

Thermal energy on both indoor and outdoor loops are measured by Brunata energy meters, and 5 Carlo Gavazzi electric energy meters are used for the heat pump compressor, the outdoor circulation pump, the two indoor circulation pumps, the electric resistance in the storage tank, and the 4 fan coil units, respectively. All equipment is placed in a control box (see Figure 12). The data measured by these energy meters, as well as by an outdoor temperature sensor and a solar radiation sensor, are transmitted to a National Instruments controller, which also communicates with the heat pump controller (for data acquisition only).

Fig. 13 – The control box

CONCLUSIONS

GROUND-MED European project is an ambitious project that involves more than 20 partners from almost all European countries and aims to develop ground source heat pump systems that have higher seasonal performance factor than the ones used today. One of the 8 demonstration systems is located at University of Oradea. At an initial stage, a large building was chosen to be heated/cooled with this new system, but its poor insulation and old window frames extremely increased the heat losses of the building. Therefore, this building became inappropriate for installing a ground source heat pump system of medium capacity (20 -80 kW). We focused then to another building, a smaller one, having a heat loss of about 40 kW.

For the base heating load, the highest specific heat extraction rate is in January (6.17 W/m) and the lowest is in September (1.06 W/m). Speaking of peak heating loads, the maximum value is 27.64W/m. For cooling, specific heat injection rate is 19.64 W/m.

Therefore, depending to the outside temperature conditions, we may have two scenarios: either the weather conditions are mild and the system will run base load, or – the worst case scenario – when the system has to run continually for several hours at maximum heat capacity and then, of course, specific heat extraction will be maximum. Consequently, the fluid output temperature will decrease substantially if peak loads occur.

For instance, after 20 years of running base load, the minimum fluid temperature is at the end of January (7.52 °C), but if the heat load occurs, the temperature will drop 6 °C, reaching 1.41 °C. The fluid temperature in every months of the heating season will decrease comparing with the temperatures for base heating load. If we take into consideration the cooling peak loads, the fluid temperature will be higher in summer months (July, August) comparing to the base load.

After running the simulation and getting the fluid temperatures, we can conclude that the initial data are O.K. and the system will run with a SPF factor of at least 5.0.

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