Ground Source Heat Pump on Building Acclimatization in Coimbra, Portugal

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Abstract. The purpose of this paper was the study of different scenarios to the development of the Portuguese demonstration site of GROUND-MED project. This is one of the eight demo-sites in this project which runs under the Seventh Research Programme. The analyses done to the building regards only the energetic component. The first part of the work consists on the thermal simulation of the buildings third floor, done to help in the dimensioning and selection of HVAC components based on the demand of cooling and heating. The second part of this paper concerns the type of boreholes and boreholes heat exchangers selection, taking into account the soil characteristics and acclimatization needs. The simulation of thermal needs was performed in EnergyPlus and the geothermal calculations with the Earth Energy Designer (EED). Many configuration and dimensions are suggested, aiming economical benefits and thermal maximization for the local ground conditions. According to the EnergyPlus calculations, the studied space annual thermal needs totalize 26 MWh in cooling mode and 4.5 MWh in heating mode. The power demand peak is about 48 kW in January and 56 kW in July. To this needs EED calculations showed that 4 boreholes heat exchangers with 107m each are sufficient.

Key words

Ground Source Heat Pumps, Acclimatization, Geothermal Energy, Borehole Heat Exchanger

1. Introduction

The Advanced Ground Source Heat Pump Systems, for Heating and Cooling in Mediterranean climate (the GROUND-MED project), aims to demonstrate the effectiveness of next generation geothermal heat pump (GSHP) systems for heating and cooling in 8 different demonstration sites across South of Europe [1].

One of the GROUND-MED project objectives is to design and monitor a high efficient ground source heat pump, with a measured seasonal performance (SPF) higher than 5 considering operating conditions imposed by both the ground heat exchanger and the building heating/cooling system.

The Portuguese site is located at the northeast bank of Mondego River in Coimbra, a few meters from the margin. The selected building was an old milling factory, converted into the Regional Hydrographic Authority building (ARH), and is mainly composed by offices and laboratories.

Figure 1 shows the building location.

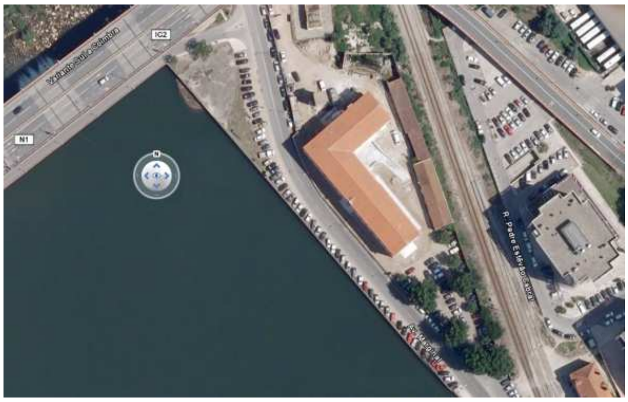

Figure 1 – Coimbra site location (Google Earth)

A notable aspect of this building is its particular characteristics, due to the fact of being a recovered old building, with limestone walls which thickness goes from 0.6 to 1.1 meters. The third floor has the thickest wall with “only” 0.6 meters wide. The wall layers are showed in figure 2.

The ground source heat pumps that will be used on this demonstration site will be developed by CIAT, as well as the new fan coil, and have being developed to distribute air at moderated temperatures.

Figure 2 – Wall layers (3rd floor) DesignBuilder figure

The work developed in this paper is divided in two different parts. The first part consists on the thermal simulation of the building third floor to help in the dimensioning and selection of HVAC components based on the studied area demands of cooling and heating. The second part concerns the type of boreholes and boreholes heat exchangers selection, taking into account the soil characteristics and the acclimatization needs calculated in the first part. The results of both parts are achieved through numerical simulation software's, considering the real properties of the building, soil and climatic conditions. This study is just a case study based on Coimbra demo–site of Groundmed project.

2. Case Study (Thermal needs)

All the dimensions and characteristics used in the thermodynamic simulations of this building were collected or measured in loco. The envelope materials used on the thermal simulation were identified at the building or from the rebuilding project and are described in table 1.

Table 1 – Walls materials properties

Exterior Wall 3rd Floor			
Layer material	Thickness (m)	Conductivity (kJ/h.m.K)	Density (kg/m^3)
Gypsum sand render	0.015	2.88	1600
Cement sand render	0.05	3.6	1800
Limestone	0.5	6.12	2200
Cement sand render	0.05	3.6	1800

The windows of this floor are of tree types. The first type is a wooden door with clear simple glass. The second type is a standard aluminium frame double glassed window without solar shading (figure 3 – B). The third type is a special handmade glass, without frame, being the external glass clear and the internal one hand painted (figure 3 – A).

Figure 3 – Two types of windows on the 3rd floor

Because it was not possible to acquire the glass real solar factor and global thermal heat coefficient (U) some calculations were made. The simulation was made with common and medium values, of those two characteristics, to the three different kinds of window. The solar factor used was equal to 0.42 and the global thermal heat coefficient was 3.74 $W/m^2.K$.

Those values could have some influence on the thermal loads demand and total electric consumption, however they seem realistic or even favourable hence the solar factor achieved is lower compared with the solar factor of the standard double glassed window that represents about 50% of the glassed area of that floor, like it can be seen on figure 4.

Figure 4 – The building

The U values of the surroundings, the global solar value, the workers schedules and the occupation densities were evaluated by on-loco observation and analysis.

The new GSHP will acclimatize the entire 3rd floor (upper floor), which spaces are now being served by an air-to-water pump, for cooling and heating.

It is supposed to obtain a cooling and heating capacity similar to that of the actual HVAC equipment serving this floor. The GSHP should be connected to the available air handling unit(s) for these spaces.

3. Results (part 1)

The 3D building model was created in DesignBuilder software, a graphical interface of EnergyPlus (version 6) [2]. The 3D representation is showed in figure 5.

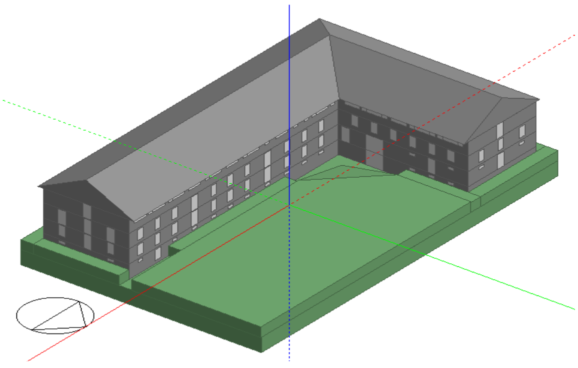

Figure 5 – 3D model of the building

With this program it is also possible to determine the lights and equipment consumption and the occupant's loads. In spite of not being an objective of this study, this work was also performed.

In the development of the project it was necessary to design and characterize the whole building to find all floors power demands.

This kind of program helps to determine the peak capacity needed to each type of thermal energy (cooling and heating).

It´s possible to see some results in figure 6. The power peak of the lights and equipments it´s also calculated, as well as the total consumption of each type of energy in kWh.

The third floor has a total of twenty two offices, with 970 square meters pavement, 613 of which are acclimatized, simulated with a nominal occupation of 25 people, a lot above the real occupancy.

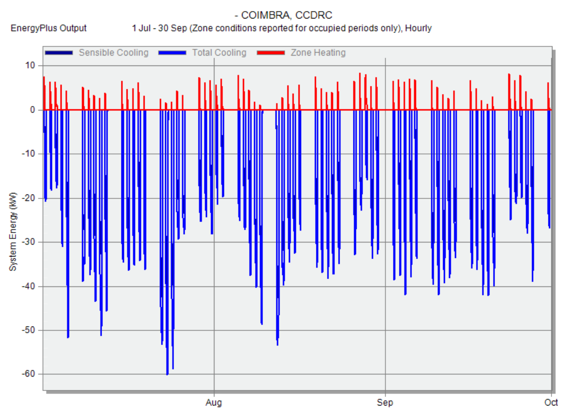

Figure 6 – Cooling and heat power demand peak (example 3 months)

The results from the simulations show that the thermal capacity needed to acclimatize the floor corresponds to 56.2 kW in cooling mode and 48.1 kW in heating mode. For the terminal units dimensioning is used a project factor of 1.2 at heating design and 1.3 at cooling design. So, the sum of each unit should totalize the value of 81.8 kW for cooling and 53.9 kW for heating.

4. Case Study (Boreholes study)

The second part of this case study is the geothermal boreholes configuration and depth for the water loops heat exchangers. These values were studied with the EED program (Earth Energy Design by BLOCON) [3].

The input data for the simulation in EED is listed below.

The ground thermal conductivity, the heat exchanger properties and dimensions used were supplied by the soil perforation company (GeoMinho) after the 1st borehole drilling. The unavailable values were chosen taking into consideration the reports from ESTSetubal GSHP similar project called GroundHit [4].

The ground thermal conductivity property was achieved considering the average value of the soil components measured during the drilling process of the 125 meters pilot borehole which components are presented in figure 7.

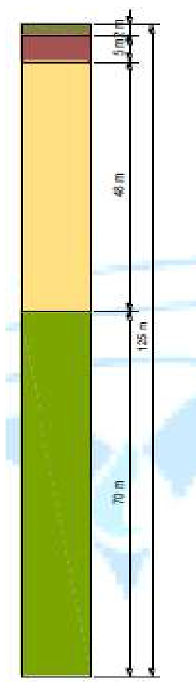

Figure 7 – Soil characteristics

The first 2 meters of soil are landfill, the next 5 meters are silt, the 48 next meters are sandy limestone and the last 70 meters are clay.

According to this ground characteristics the input values in EDD were:

1) Thermal conductivity: 2.4 W/(m.K);

2) Volumetric heat capacity: 2.16 MJ/(m^3.K);
3) Ground temperature: 15.5 ºC;
4) Geothermal heat flux: 0.07 W/m^2.

The boreholes type considered was the double U configuration. The first borehole drilled, with 125 meters depth, was the pilot one. The pilot borehole is very important to achieve the soil characteristics and decide the quantity of boreholes needed according to this characteristics and building needs [5].

Initially the space between boreholes considered was of 5m and the diameter of each borehole was 110 mm.

The resistance between pipe and filling chosen was 0.02 (m.K)/W, which is a low value that, according to the EED manual, should be used in case of unacknowledged. The filling material chosen in the simulation was dry gravel with 3 mm to 8 mm range, with a thermal conductivity of 0.4 W/(m.K).

The volume flow of 0.6 L/s for all boreholes was achieved extrapolating the Polytechnic Institute of Setúbal (IPS/ESTSetubal) data for a smaller GSHP. The number of the series factor is always 1 for this study.

The heat exchangers pipes are in HDPE – high density polyethylene – with 32 mm inner diameter and 35 mm outer diameter with a shank spacing of 56 mm. Theoretically it is better when the heat exchanger is close to the borehole wall since thermal resistance between soil and fluid is lower raising the heat transmission. However this can bring installation problems.

The borehole thermal resistance is by default, being recalculated at each run.

In this case study, the pilot borehole uses water as heat carrier fluid, but the simulations results suggested that monoethylenglicol @ 25% will be necessary to avoid freezing. The fluid characteristics used are listed on the EED fluid database.

The base loads were entered as annual energy and monthly profile, giving the monthly factor from the thermodynamic simulation.

The SPF – seasonal performance factor – of the GSHP is supposed to be at least 5. No Domestic Hot Water (DHW) is required.

The peak loads were entered manually, as well as the hour with the maximum power heat or cool demand. These values were calculated in the 1st part, the thermal needs simulation.

The running period or simulation period was set to 10 years, the warranted duration of the boreholes, starting in the beginning of a year.

5. Results (part 2)

The first part was to simulate the pilot borehole of 125 m, with pure water and a flow of 0.6 L/s for the calculated loads, using the “mean fluid temperature solver”, which generate an error message showed in figure 8.

Figure 8 – Error message from EED

The winter in Coimbra can be very severe so that problem has to be considered and it is possible that water will freeze at ground surface. One solution can be the insulation of the borehole heat exchanger pipes, however it is not possible to consider the insulation of the borehole in EED program.

To obtain the mean ground annual temperature was considered the mean air temperature along the years on Coimbra city, through the Climate Normal’s of Coimbra (1971-2000) [6]. This procedure is also recommended in the EED 3 user manual, when it is not possible to measure this value.

The minimum mean fluid temperature for the peak heat load on January was -45ºC and the maximum mean fluid temperature for the peak cool load on July was 148ºC; almost constant on the 10 years period.

In spite of this result the total depth and number of required boreholes was simulated with water as carrier fluid, using the “required borehole length solver”.

The result shows a total depth of 401.7 meters, however there was still the frizzing problem with the fluid (same message displayed), so monoethylenglicol @ 25% was added and the frizzing problem was solved being the length displayed of 410 m.

This data was used to study whish configuration suited the thermal needs, in parallel or series. It was considered a configuration of 4 in-line boreholes.

The parallel configuration results showed that a total length of 611 m was needed to achieve the thermal needs, which is above the calculated one. That´s because the Reynolds number is low and the fluid flow is laminar.

If the configuration was on series flow the total length of the boreholes should be 425 m. The higher Reynolds number and the turbulent fluid flow reduce significantly the total required length

The results of this last simulation are showed below on figure 9.

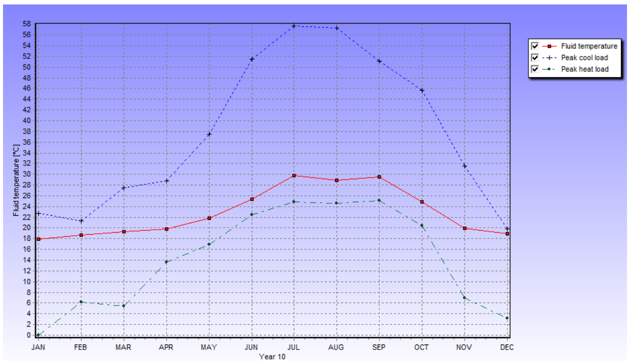

Figure 9 – Temperature profile

The minimum mean fluid temperature for the peak heat load on January was 0ºC and the maximum mean fluid temperature for the peak cool load on July was 58ºC.

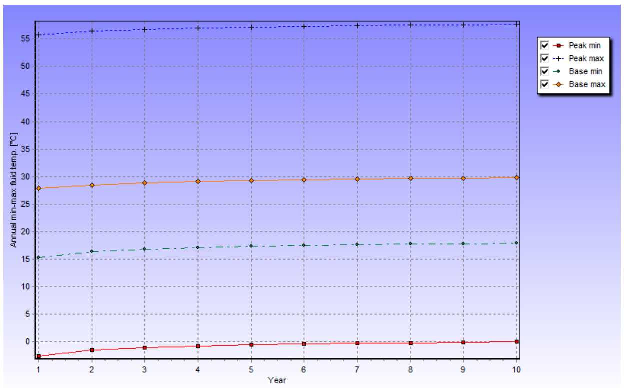

Figure 7 – 10 years temperature variation

In figure 10 it can be seen that the profile of the ground temperature evolution is flat what means that the saturation isn´t reached at the end of 10 years.

There´s a major difference between the temperature of the fluid on the base load method and on the peak load method.

Since only one hour of continuous functioning at the maximum peak load was defined, probably the fluid temperatures results of these simulations will be greater.

Optimizing the length it was possible to conclude that the best solution is 2 boreholes in parallel with 418 meters.

It was not taking into account the pressure loads in this different configuration that is more favourable for 4 boreholes in parallel.

The economical evaluation is important to help on the configuration, considering the soil available space for drilling and the fluid flow rate. It is important to reduce this flow because it raises the electrical pumping consumption.

Considering this and having the intention to reduce the pumps consumption another simulation was done. With a parallel flow of 0.15 L/s per hole, 4 in-line boreholes with total length of 611 m.

Another project theme that might be present on further studies is the thermal energy storage.

The solutions available in the market, aren´t as useful as needed in the standard forms so it will be necessary to carry on with some research and simulation work.

Those results will help to find out which kind of materials, and what type of reservoirs could be applied to accumulate available or cheaper energy, to be used in the most critical periods regarding the earth saturation on peak load periods. The utilization of this kind of solutions will allow the reduction the total length of the boreholes reducing the installation cost without compromising the thermal needs of the building.

There are many materials with several shapes and melting temperatures, some appropriated for cooling and others appropriated for heating, the phase change materials (PCMs).

For instance the inorganic salts with a 32ºC-35ºC melting point with a spherical shape for heating, and the organic mixtures with a 5ºC-16ºC melting point in a flat container for cooling are good solutions for this application, given the working temperatures of a GSHP.

Another great innovation in this project is the implementation of the moderate temperature fan coils and air handling units by CIAT, in the acclimatized spaces. This allows increasing the energy efficiency contributing to the exploration cost of the acclimatization system.

The air distribution inside each space needs to be studied using a computed fluids dynamics (CFD) program (like Fluent), to model a typical office with typical fan coils distribution effectiveness.

6. Conclusions

The aim of this work was to simulate some case study taking into account the characteristics of Groundmed project Portuguese demo-site. Some calculations concerning the building energetic needs and the boreholes heat exchanger number and configuration were performed.

From the results of the energetic study, it was possible to achieve the thermal capacity needed to acclimatize the space, which corresponds to 56.2 kW in cooling mode and 48.1 kW in heating mode. Considering a design heating factor of 1.2 and a cooling factor of 1.3 for the terminal units, the sum of each unit should totalize the value of 81.8 kW for cooling and 53.9 kW for heating.

For these needs and concerning the boreholes configuration and length study, it was possible to see that the best configuration is in parallel and considering a total length of 611m, only 4 boreholes in-line were needed. Other important aspect is the fact that, regarding the site climate, simple water is not a good carrier fluid since it freezes, so it is necessary to use monoethylenglicol.

The initial cost of this kind of installation can be reduced using thermal energy storage for cooling and heating by using the PCMs.

The exploration costs can be reduced using moderate temperature fan coils and air handling units.

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