Improvement of the Energy System Efficiency by a Ground Source Heat Pumps System in a Sport Center

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ABSTRACT

This paper presents the project and the economic and environmental evaluation of a ground source heat pump system implemented in a sport centre located in Sora (Italy). The first step of the work has been the estimation and the analysis of the energy consumption of the building, using the energy bills to validate the results. In order to improve the energy system efficiency, three different solution have been proposed and analysed. The first option consists of a geothermal plant and a solar panel plant. The second solution includes a CHP system in order to satisfy the electrical request of the heat pump. The third solution is composed by the geothermal and solar plants, the CHP system and the condensation boiler to produce the remaining thermal power. The three solutions have been compared by the economic point of view and the environmental one. The results highlight that the first option (geothermal + solar system) is not economically favourable. Instead, considering the national subsidy, the two hybrid plants show a positive cash flow due to the boosting received by the CHP and the condensation boiler.

1. INTRODUCTION

Following the well-known energy strategy 20-20-20, the European Union take the decision to cut the total energy consumption by 20%. The residential building and tertiary sector is responsible of the 40% of the energy use in Europe. A paradigm change is needed to reduce the required energy in heating & cooling a building. The key issue is the recovery of the architectural background through the bioclimatic concepts.

In Italy the residential buildings are, based on the 2011 ISTAT census, 12.2 million with more than 31 million of homes. More than 60% of them is older than 45 years. Those building have been built before the first law on the energy saving. The 30% of those buildings have been built before the Second World War. Due to their different period of construction, the buildings have various construction features. Therefore, they have different energy performances. ENEA (2010) gives a division of the energy use where the 70% is for heating, 16,5% for lighting and 13,5% for electronic/electrical devices. There are many barriers to the diffusion of the efficiency improvement through the country.

The technical barriers concern the inhomogeneity in applying standards and regulations like different administrative costs and required documentation. The economic and financial barriers are related to the high complexity of the technical-economic evaluation of the intervention that leads to medium-long payment times for accrued interest rates. Also, the uncertainty in forecasting the energy costs on which the economic flows depend and shortage of subsidized loans have their influence.

The retraining, global or partial, can take place through the following main interventions: thermal insulation of the building envelope; perimeter opaque walls, reduction of thermal bridges, inter-floor slab, roof slab; window and door replacement; blackout elements, insulation, high energy performance fixtures; lighting system replacement; high efficiency lighting bodies; installation of a home automation system (intelligent home management); installation of the air conditioning regulation system; replacement of the heat production system; use of RES.

Energy efficiency is of great importance when it comes to renewable sources. RES at the moment are not able to completely cover the energy demand, and in parallel with the development of technologies one can try to change the same energy demand. In fact, by decreasing the demand for energy, a plant powered by renewable sources assumes greater importance. In this work will be described, studied and proposed the use of Geothermal Energy as renewable energy for the air conditioning of a sports center located in the Lazio, province of Frosinone.

2. THE CASE STUDY

The sport complex covers a 5000 m^2 surface and two distinct buildings form it, one is the fitness center and the second one is the indoor swimming pool. The two main buildings are connected together through the locker room area where the technical room is also located. The fitness center is a three floors building with a concrete structure with a surface of 1220 m^2 and a volume of 4000 m^3. The swimming pool is a wood structure with a surface of 740 m^2 and a volume of 4300 m^3. The activity is six days per week with an average of 286 days per year. The actual plant for thermal energy production is based on gas heater (see Table 1).

Table 1: Thermal power plant.

Heater	Heat power	Net power
ARCA-PKR350 backup	281 kW	260 kW
UNICAL-TZ AR250	322 kW	291 kW
UNICAL-TZ AR250	322 kW	291 kW

For cooling needs the sport center is supplied by conventional air conditioning devices (see Table 2). The electrical energy consumption is also due to the swimming pool technical plant, water supply system, lighting, fitness machines, and other electrical uses.

Table 2: Cooling power plant.

Mitsubishi PU-4YJSA	6 units	First floor
Mitsubishi PU-6YJSA	4 units	Second floor
AERMEC CX91H	2 units	Third floor
Mitsubishi PU-4YJSA	6 units	First floor

The energy consumption in terms of gas and electrical supplies have been fed by the administration by the billing system. In order to evaluate the possible integration of RES into the power plant of the complex, a model has been built. The thermal load evaluation has been divided for the different uses: heating, sanitary water and swimming pools heating. To evaluate the required thermal energy, the DIVA for Rhino plug-in has been used. The software output is the monthly energy needs to be fed in order to satisfy the comfort conditions. The 3D model has been built taking into account the surrounding buildings, the construction material and the different zones of the sporting center (Fig. 1). The Fig. 2 shows the results of the calculations for the heating needs divided for each different zone.

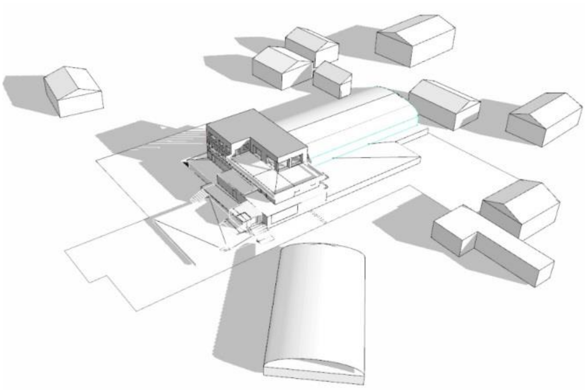

Figure 1: 3D model of the sporting center.

The second component of the heating needs are the two swimming pools (see Table 3).

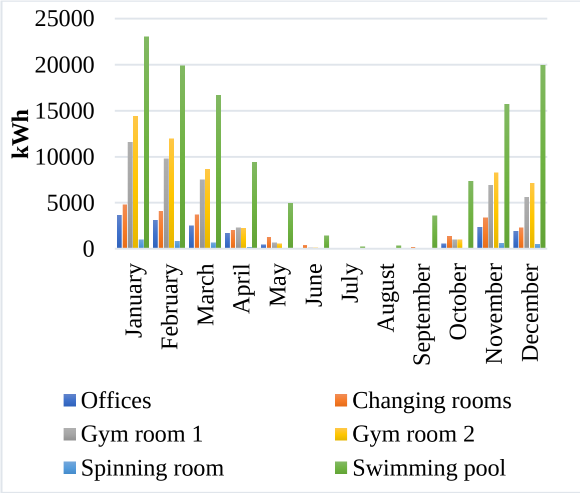

Figure 2: Building heating demand.

Table 3: Swimming pools.

	Large	Small
Volume (m^3)	350	19
Gross surface (m^2)	250	32
Temperature (°C)	29	30
Heat exchange coeff. (kW $°C^{-1}$ m^{-2})	0.2	0.2
Daily water change	2%	2%

The heating to be supplied to the water is divided in three different processes corresponding to different operating conditions: start-up, replenishment and thermal dispersion. The monthly required energy has been evaluated for both swimming pools and reported in Fig 3.

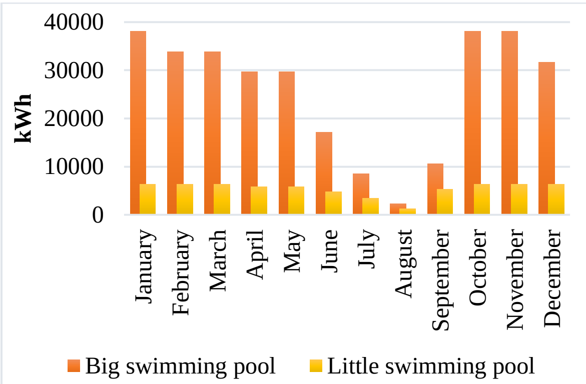

Figure 3: Swimming pools heating demand.

The required volume of sanitary water has been evaluated referring to the UNI-TS 11300-2. The more consuming activity for sanitary water are the showers. A special attention has been paid in calculating the required volume. Summarizing, the thermal consumption previously calculated has a deviation of 6-8% from the values reported by billing.

The electrical load is mainly divided in two parts: the general uses and the cooling system. The evaluation of the electrical load due to general uses has been done by knowing the installed power and the timing. Always by the DIVA add-on for Rhino the required energy for cooling has been calculated. In Fig.4 are presented the monthly cooling loads.

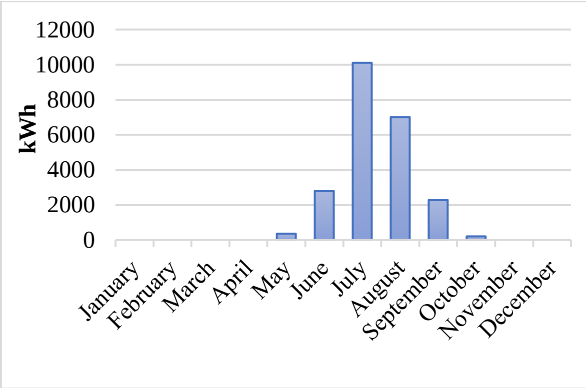

Figure 4: Building cooling demand.

3. GSHP PLANT DESIGN

Different approaches can be adopted to size the GSHP power plant. First step is to evaluate the heating/cooling demand of the building. After, the balance between the heating and the cooling load is the driving concept to be adopted. In this case, seeking the highest efficiency of the plant, the choice of the heat pump sizing is nearly obliged: the GSHP plant will fully satisfy the cooling demand. In the winter season, the GSHP plant with the gas boiler will satisfy the heating demand.

Therefore, sizing the heat pump to satisfy the maximum cooling load (July) the chosen heat pump will have 42.8 kW in heating mode and 34.2 kW in cooling mode (see Table 4)

Table 4 – Heat pump technical data

	Heating	Cooling
Power (kW)	42.8	34.2
Electrical power (kW)	9.28	
COP/EER	4.6	3.69

3.1 Vertical geothermal probe

In order to design the vertical geothermal probe field coupled with the heat pump, the available stratigraphy and literature (Panizio) was analyzed and the ground properties evaluated. The average thermal conductivity of first hundred meters of ground is 2.4 $Wm^{-1}K^{-1}$ and the thermal diffusivity is 4.3956 10^{-4} m^2day^{-1}. The undisturbed average temperature of the ground is equal to 13.7 °C.

Some other assumption has been made in order to proceed in sizing the heat exchanger. The working fluid is a mixture of water and propylenic glycol at 25%, with a specific heat at constant pressure of 3920 $Jkg^{-1}K^{-1}$. Regarding the limitation introduced by the heat pump, the most important is the minimum inlet temperature. To avoid the ice lensing effect this temperature was fixed at the value of 0 °C. In cooling mode, for the maximum inlet temperature the value of 20.5 °C was chosen. Single U polyethylene tubes of 40 mm diameter and 3.7 mm width form the geothermal probe. A bentonite-cement mixture having a thermal conductivity of 1.63 $Wm^{-1}K^{-1}$ constitute the grouting.

The probe field will be realized in car parking near to the swimming pool. The total length of the probe field has been evaluated on the base of Kavanaugh-Rafferty method (2014). Table 5 reports the calculated values of the length in heating and cooling mode. Following the assumption to give priority to the cooling demand, the length of the heat exchanger will be the cooling mode length, which is the longer one.

Table 5: Probe sizing length

L heating	1247 m
L cooling	1518 m

The distance between the probes is 10 m to contain the thermal interference. Choosing the length of the single probe of 100 m, the number of probes is 15 and they are located as presented in Fig. 5.

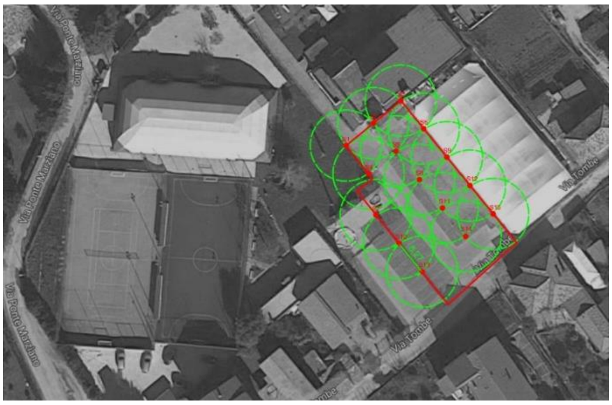

Figure 5 - Geothermal probe location in the car parking

4. PLANT SOLUTIONS

In order to retrofit the plant different possible technical configurations have been considered.

4.1 Plant configuration 1

The first configuration is based on the full coverage of the cooling demand of the buildings by the GSHP plant. The total heating demand will be covered by the GSHP and the existing gas boiler. The GSHP guarantees a total coverage of the 68% of building heating demand and it contributes to the other heating needs for three months.

A possible bottleneck is the heat balance into the ground. The cooling and heating loads are not balanced and this can produce an over/under heating of the ground. This effect has negative influence on the efficiency of the heat pump as well as on the increase of the temperature of the ground reducing the overall efficiency of the GSHP plant. Considering the COP and EER of the heat pump, the exchanged energy with ground in the heating season and in the cooling season is not balanced (see Tab. 6)

Table 6 - Ground energy balance – GSHP

Qheat	76.370 kW
Qcool	28.946 kW
dQ	47.424 kW

In the present case, the ground in a short period will produce a cooling of the ground reducing the overall efficiency of the plant. To maintain the energy balance on the GSHP reducing the working hours, the cost-benefit analysis shows a negative balance. To overcome this point, a thermal solar plant (SP) has been designed in order to allow the recharge of the ground during the summer season.

The solar panel plant has been designed assuming the available roof surface of 306 m^2. Selected the climatic data from the regulations UNI10349 and defined the optimal parameter for the inclination of the panels, the plant will consist of 15 panels for a total surface of 39 m^2 corresponding to the 4% of the available one. To obtain a more balanced working plant the heat pump production has been reduced a little in heating in order to compensate the solar panel production. In this manner the plant is able to ensure a more equilibrated energy balance into the ground (see Tab 7). This will allow a more interesting cost saving.

Table 7 - Ground energy balance – GSHP and SP

Qheat	51.313 kW
Qcool	28.946 kW
Qsp	20.030 kW
dQ	2.337 kW

4.2 Plant configuration 2

The second configuration is based on two main assumptions: the increase in electrical energy to be supplied to the heat pump; the need in thermal energy for heating needs. Thus, a combined heat and power device (CHP) has been selected to have local production of electrical energy and heat. The CHP system is based on an internal combustion motor feed by natural gas. The sizing target is the required electrical power by the heat pump. Oversizing a little bit, the chosen electrical power is 15 kW. The operating condition of the CHP is to cover the base load either for electrical and for thermal loads.

Table 8 - Combined heat and power plant

Electrical power	15 kW
Thermal power	33.1 kW
Electrical efficiency	30.50%
Thermal efficiency	66.90%

In this configuration, the heat production is obtained with three different technologies: the GSHP, the thermal solar panels, and the CHP. The heat demand is fulfilled by these “green” technologies for the 19% and the rest by the gas boiler (see Figure 6).

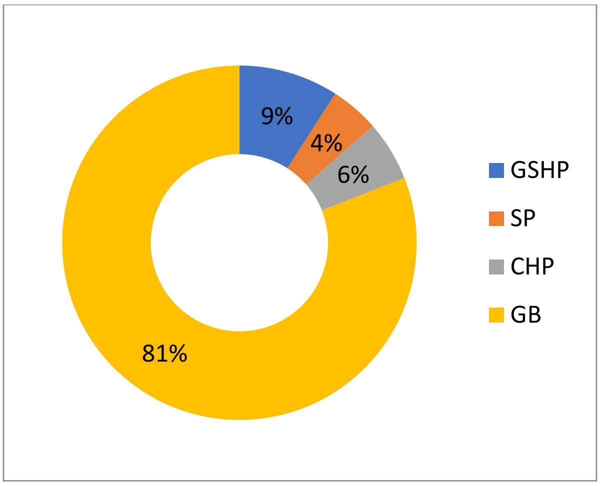

Figure 6 – Contribution of different energy plant (GSHP ground source heat pump, SP solar panel, CHP combined heat and power, GB gas boiler)

4.3 Plant configuration 3

The third configuration has been designed to reduce the gas supply. Therefore, the present gas boiler has been replaced with a condensation gas boiler (CGB). The CGB (see Tab. 9) is sized on the peaks demand and on the complementary energy required to satisfy the energy demand.

Table 9 - Condensation gas boiler plant

Thermal power	285 kW
Efficiency	105.00%

5. PLANT SOLUTIONS COMPARISON

The compare the different configuration of the plant two different methods have been used. The first one is a classical business plan with the economical evaluation of the profitability of the investment. The second method is a multi-criteria method that combines not only the economics of the project, but also the environmental and efficiency aspects.

5.1 Business plan assessment

Starting from the previous three configurations, the business plan assessment is evaluated for each of them.

For all plant configurations the initial cost is spread between Debit and Equity in the proportion 70-30 with a debit cost of 5% yearly and an equity cost of 15% yearly. The debit return time is fixed at 7 years, smaller than the lifetime of every considered plant.

The income corresponds to the saving costs for gas and electrical energy. The expenses are the operative and maintenance costs as well as the instalment banking. The discounted cash flow has been calculated using the WACC. The bank instalment is calculated with the French method.

The net present value (NPV), the internal rate of return (IRR) and the payback period (PBP) were adopted as indicators of the economic nature of the various proposals. It should be noted that all indicators and economic considerations were made over a 12-year period.

For the further considerations the cost of electrical energy has been fixed to 0.23 €/kWh and for the gas 0.80 €/Nm^3 with a Lower Calorific Power of 9.6 kWh/Nm^3.

5.2 Configuration plant 1

The configuration considers a GSHP plant combined with a SP plant and the existing gas boiler to supplement the energy demand of the sporting center.

From the technical evaluations a cost saving of 6,850 € is obtained. Further incomes are obtained by government incentives. For the GSHP plant, the more convenient incentive system is the Fiscal detraction with an annual rate of 10,000 €. The save evaluation for the solar panels gives an incentive of 6,630 € per year.

The total investment cost, corresponding to the sum of the two plants cost, is 205,748 €, and the annual rate based on the previous assumptions is 37,994 €. From the economics is clear that all indicators are negative and the PBP is over 30 years (see Tab. 10). The DSCR is 0.71 less than unit.

5.3 Configuration plant 2

The introduction of the CHP plant gives more incentives due to the cogeneration of electrical and thermal energy. The cost of the gas for this application is 0.30 €/Nm3.

The cost saving in this case is greater and equal to 26,560 €. The incentives on the GSHP and SP plant are the same than configuration 1 but should be added the incomes for the CHP plant. For this plant are valid the white certificates. The evaluation gives nine white certificate per year with a price of 275.79 €/WC corresponding to 2,618.58 € per year.

Adding the cost for the CHP plant the total investment is 220,748 € with a yearly rate of 40,764 € a PBP less than 7 years. The main economic indicator are reported in Tab. 10.

5.4 Configuration plan3

This last configuration has the upgrade of the present gas boiler with a condensation gas boiler. The choice of the CGB gives an increase of the total efficiency of the plant due to the reduced gas consumption.

The income is growing up to 33,667 € including the incentive for the purchase of the plant. The investment also is growing and the total cost is 250,748 € with a yearly rate of 46,304 €.

The economic indicators give us the idea that this solution is very near to the previous one always highly efficient (see Tab. 10).

Table 10 – Economic analysis comparison

Economic indicator	Config 1	Config 2	Config 3
VAN	-57,452 €	102,026 €	113,491 €
PBP	> 30 years	6.2 years	6.8 years
TIR	-0.096%	16.05%	15.16%

5.5 Multicriteria analysis

The better technical solution is not necessarily the most economically efficient but it should satisfy also other aspects like environmental ones. To comply this task, a multi-criteria analysis has been conducted. The parameter taken into account are the VAN, the initial investment, the TIR, the PBP, the CO2 emissions and the primary energy consumption. Each of these parameters has been normalized with respect to the solution that presents the best value for each parameter; after each normalized value, a weight has been assigned to make the choice on the solution that presents the highest value of the weighted average of the normalized parameters fall.

To evaluate the gas emissions, the UNI-TS 11300 part4 was used, taking as reference the standard emission as function of the energy vector.

The calculation of the heating and cooling energy produced from renewable sources for the heat pump was carried out following the indications proposed in the Position Paper by AICARR with respect to Legislative Decree 28/2011.

For the calculation of primary energy, reference was made to the table of conversion coefficients for different energy carriers reported in Table 7 UNI-TS 11300 part 4.

Since Configuration 1 is not economically feasible for the analysis in question, only the other two configurations are taken into consideration. In Table 11 are reported the parameters in absolute value and also in normalized version.

The best solution is therefore represented by Configuration 3, despite the high initial cost, involves a reduction in emissions and the primary energy index consumed by renewable sources that justifies the higher investment cost.

Table 11 – Multi-criteria analysis

	Initial cost	VAN	TIR	PBP	Emissions	EPRN	
Configuration 2	€ 204.868	€ 102.027	16,05%	7	266469 kg of CO2	831	
Configuration 3	€ 250.748	€ 113.491	15,16%	7	209807 kg of CO2	751	
Weight	0.3	0.25	0.05	0.05	0.15	0.2	
Configuration 2	1.00	0.90	1.00	1.00	0.79	0.90	0.9234
Configuration 3	0.82	1.00	0.94	1.00	1.00	1.00	0.9423

6. CONCLUSIONS

In this paper the implementation of a Ground Source Heat Pump system in the energy plant of a 70's sporting center has been studied. None energy upgrading on the building has been accounted, therefore the main challenge of the evaluation was to find a plant solution for a low energy efficiency building.

The starting point of the work has been the estimation and the analysis of the energy consumption of the building, calculated using the energy bills to validate the results.

The possible integration of RES into the plant of the complex has been studied using a 3D model built with the DIVA for Rhino plug-in. The thermal load has been divided for the different uses: heating, sanitary water and swimming pools heating. The electrical load is mainly divided in two parts: the general uses and the cooling system. The results provide the monthly thermal and electrical need.

The GSHP plant has been designed to fully satisfy the cooling demand during the summer season, whereas in the winter season, a gas boiler will compensate the heating demand not covered by the GSHP plant. The chosen heat pump has a nominal power of 42.8 kW in heating mode and 34.2 kW in cooling mode. The geothermal field is composed by 15 single-U probes with the length of 100 m for each element.

In order to retrofit the plant different possible technical configurations have been considered. The first option consists of a geothermal plant and a solar panel plant that recharges the heat losses of the ground. The second solution includes in the previous configuration, a CHP system in order to satisfy the electrical request of the heat pump. The third solution is composed by the geothermal and solar plants, the CHP system and a gas condensation boiler to reduce the gas supply.

The three solutions have been compared using two different approaches: the economic analysis and the multicriteria analysis, which includes the VAN, the initial investment, the TIR, the PBP, the CO2 emissions and the primary energy consumption.

The economic analysis discourage the adoption of the first solution composed by the GSHP and the PV plant. The second and the third solution have very near economic indicators. Therefore the multicriteria analysis has been conducted only for the solution 2 and 3, showing that the best option is represented by the Configuration 3. Despite the high initial cost, the system that combines geothermal plant, photovoltaic plant, CHP plant and gas condensation boiler assures a reduction in emissions and the primary energy index consumed by renewable sources.

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