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Evaluation of efficiency of hybrid geothermal basket/air heat pump on a case study winery based on experimental data

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ABSTRACT

In wine-making sector, processes require high cooling loads for short periods; in addition, the climate-dependent energy needs have to be added. In Southern Europe latitude, a combination of Air Source Heat Pumps to cover peak cooling loads and lpg-fired boiler for winter heating is the most common solution for wineries in countryside, which are usually off-gas grid. Shallow geothermal energy coupled to heat pumps could represent a good solution for wine-making sector, and some applications exist in different countries. Nonetheless, because of electricity price and the displacement between high cooling and low heating loads, the investment cost for the geothermal field often is not justified. Some cheap and shallow solutions as geothermal baskets can help to reduce investment costs, but their capacity is limited, so to cover the entire cooling loads represents a significant task. On the other hand, a combination of different technologies could bring to interesting results in terms of cost and CO_2 savings. The paper presents an efficiency evaluation of a hybrid solution integrating a Ground Source Heat Pump coupled to geothermal baskets with an Air Source Heat Pump. An experimental campaign – Thermal Response Test – was conducted in the courtyard of a winery. A simulation program tailored on the test results has been realised for the specific case study, in order to optimise the integration between two plants. It was then possible to determine the energy savings connected to the use of the hybrid solution with respect to alternatives, to cover the entire heating and cooling needs of the winery.

1. Introduction

Ground Source Heat Pumps (GSHPs) are a combination of a heat pump and a number of Ground Heat Exchangers (GHEs), which exploit/inject heat from/into the ground, through the circulation of a working fluid in a closed loop circuit [1]. The GHEs use the insulation potential from weather conditions of the ground, increasing along depth, to provide significant heat transfer between the soil layers and the working fluid [2].

Several possible configurations of GHE exist, depending on the shape, geometry and material of the pipes and on the consequent installation technique into the ground. As regarding the shallowest GHE, which offset the thermal influence of ambient conditions with reduced installation costs with respect to deeper ones, the common configurations are the horizontal collectors [3], the slinky coils [4], the geothermal baskets [5] and the helical heat exchangers [6]. They are installed through excavations and in some cases by dry auger drilling; they can even be inserted into the foundation structures of buildings [7] and infrastructures [8]. The penetration depth into the ground does not generally exceeds 10 m. Deep GHEs are the Borehole Heat Exchangers (BHEs), which are installed through drilling, with the common add-on of drilling fluids (air or water, depending on the soil and rock types and groundwater conditions [9]).

Abbreviations: TRT, thermal response test; M-TRT, thermal response test machine; ILS, infinite line source; GSHP, ground source heat pump; ASHP, air source heat pump; COP, coefficient of performance; EER, energy efficiency ratio; SPF, seasonal performance factor; GHE, ground heat exchanger; BHE, borehole heat exchanger; VPN, virtual private network; GW, gateway; AGR, aboveground; PUG, partially underground; HdPE, high density polyethylene.

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Nomenclature

σ	Standard deviation
μ	Mean
E	Energy (kWh)
P	Power (W; kW)
Q	Flow rate (m^3/s; l/h; kg/s)
t	Time (d)
T	Period of simulation (d)
T	Temperature (°C)
D	Spacing (m)
N	Number (–)
V	Maximum amount (kg/l; %)
H	Equivalent working hours (h)
COV	Coverage (kWh; %)
c	Specific heat (J/(kg K))
ρ	Density (kg/m^3)
R	Thermal resistance (K/W)
W	Insulated water tank
F	Safety device
U	Electronic control unit
B	Basket
I	Basket inlet
O	Basket outlet
a	Regression slope
b	Regression intercept
x	Hour of simulation
n	Number of elements for each time step
N	Total number of elements

Subscripts

a	Air
g	Ground
f	Circulating fluid
fer	Fermentation
sim	Simulation
vol	Volumetric
c	Cooling
h	Heating
us	User
in	Inlet
out	Outlet
min	Minimum
max	Maximum
b	Basket
on	Functioning
GSHP	Ground source heat pump
ASHP	Air source heat pump
el	Electric
comp	Compressor
circ	Circulation
m	Mass
D	Design
p	Constant pressure
TRT	Thermal response test
corr	Corrected
co	Charge only
hp	Heat pump
0	Initial
x	Hour of simulation

BHEs are universally considered more efficient than shallow alternatives in exploiting/injecting heat from/into the ground [10]. The reason lies in the fact that they can relatively easily be placed everywhere and then reach relevant depths because of their vertical geometry, up to many hundreds of meters; therefore:

- if no drilling restrictions persist, the GSHP designers can decide for each borehole the optimum width of the heat exchange side area, according also to the effective available space at the surface for the installation of the geothermal field;
- heat exchangers can reach the so-called "neutral zone" where temperature is not influenced by weather conditions but it is constant over the year [11]; the "neutral zone" can usually be found among 15 and 30 m, varying according to the soil thermal properties [12]. Descending, geothermal gradient, with temperature increasing with depth, becomes relevant, affecting the BHE performance. Deep BHEs are generally used in GSHP projects with prominent heating needs;
- thermal behaviour of circulating fluid within the BHE can be finally affected by advection phenomena related to the groundwater presence. The possibility of descending to the confined aquifers increases the rate of heat exchange and speeds up the recovery period between two heat pulses, improving the overall efficiency of GSHP.

Among all possible configurations of BHE, the most common on the market are 80–100 m deep and 127–152 mm width, with single or double PE pipe. They currently represent an effective compromise between an efficient fulfilment of prominent heating needs and the containment of the available space at the surface and the drilling costs.

Because of these peculiarities, the BHE configuration is particularly efficient in GSHP projects when energy needs are prominently dependent on weather conditions. This is the typical case of heating and cooling of buildings. In general, the typical BHE is usually able to exploit from 4 to 5 kW of thermal power, without causing significant underground energy depletion on the long period.

With respect to all other alternatives, the main barrier limiting the choice of BHEs concerns the drilling, since it needs qualified professionals and high quality standards, to ensure safety and environmental protection. This leads to high initial investments in GSHP projects, with percentages varying per labour cost in different countries. In many soil and rocky conditions, the installation of BHEs can face high drilling costs, compared to the investment costs for fossil fuel burners, making unattractive to many end-users the selection of GSHP. In most countries, state and local incentives are provided to favour the choice of GSHP with respect to fossil fuels alternatives, and so encouraging the use of low environmental impact and energy saving technologies.

The shallow GHEs fall in the surface and shallow zones of underground, affected by ambient weather (daily and seasonal temperature variations, irradiation, wind speed, rainfall, snowfall, etc. . .). The shallow GHEs increase the heat exchange surface thanks to the spiral geometry exploiting more energy per meter of excavation with respect to vertical configuration.

The installation of shallow GHEs, through simple excavation, is generally economic with respect to BHEs, but their convenience is strongly reduced due to the following main issues:

- to cover heating and cooling needs the efficiency of GSHP is lower than the solution with BHE because of the weather influence on the underground. This affects the energy costs related to the working of the compressor of heat pump;
- each GHE, because of the limited depth, exploits a very limited total power from underground (basically 1–2 kW, varying according to the external conditions). Therefore, a larger number of shallow GHE is needed with respect to BHE configuration. The