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Feasibility study of a geothermal energy system for indoor swimming pool in Campi Flegrei area

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ABSTRACT

Technologies based on a renewable energy source can be an optimal solution to the heating of a swimming pool, which can be very expensive in terms of energy demand. In this work, the energy demand of a swimming pool located in Campi Flegrei area (Naples surroundings, Italy) is supplied by a geothermal plant. Campi Flegrei are a very advantageous location for a geothermal plant installation at either low or medium temperature. Temperature gradient of the ground is usually equal to 0.03 K/m, but in the Campi Flegrei area it is significantly larger. With the exception of hottest areas, which are characterized by steaming ground, thermal springs and fumarolic emissions, a good value is equal to about 0.2 K/m. The swimming pool is 25.0 m long, 17.0 m wide and it has an average depth of 1.80 m. Building thermal loads are evaluated by means TRNSYS®. The energy demand for water heating is evaluated taking into account heat losses from pool surface and for water evaporation. The geothermal system is designed taking into account the geological and hydro-geological characteristics of the site, the characteristics of the geothermal plant and energy conversion system. A cost analysis is also presented which shows that the whole setup is economically satisfactory.

1. Introduction

One of the most popular types of sports facility is the indoor swimming pool used for Olympian races, diving, water polo and recreation. The energy consumption in indoor swimming pool is relatively higher than sports halls and outdoor pools, due to specific indoor conditions. Pool water heating and ventilation of the pool hall are the main energy [1].

The energy conservation and indoor comfort conditions represent an important challenge for many researchers. Many studies focus on the exploitation of renewable energy sources to satisfy the high demand of energy. Geothermal energy is produced by geological sources of heat and can be considered a form of alternative renewable energy. Earth's interior natural heat flow is due to both the natural nuclear decay processes of radioactive elements such as uranium, thorium and potassium, naturally contained within the Earth's mantle and crust and the primordial heat given off from the formation of the Earth [2–5]. The hottest areas of the Earth's surface are near tectonic plate boundaries, which are often associated also with volcanoes and seismic activity and where hot magmatic bodies are present. Today, geothermal energy accounts for less than 1% of world energy production. However, several studies have demonstrated that the potential geothermal energy contained on our planet is around 12.6×10^7 ZJ and that with the current technologies it would be possible to use "only" 2×10^3 ZJ. Global energy consumption amounts to a total of 0.5 ZJ per year, therefore geothermal energy itself could meet the planetary energy needs by providing clean energy for the next 4000 years [6]. Direct use of geothermal heat and water dates back thousands of years and it continuous today. The Romans, Chinese, and Native Americans left clear proofs that they used geothermal water for heating, cooking and for therapeutic purposes. Where accessible, natural hot waters have been used for space heating in cold areas and seasons. Today geothermal water is used for many different applications, depending on the temperature of the water, including electricity generation, which is the most important form of utilization of high-temperature geothermal resources (> 120 °C). Heat demand represents a significant share of final energy consumption for space heating, especially in cold countries, as well as agricultural and industrial processes. Geothermal heat production systems may meet the demand simply providing fluids at the required temperature. Geothermal resources, as opposed to hydrocarbons-based ones, are generally renewable since the circulation of heat and fluid is continuous. There is a constant terrestrial heat flow to the surface, then to the atmosphere from the immense heat stored within the Earth, and fluid enters reservoir from the recharge zones or,

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Nomenclature

c	Heat capacity (J/kgK)
P	Price (€)
IRR	Internal rate return (€)
k	Thermal conductivity (W/m K)
L_V	Latent heat of vaporization (J/kg)
m_e	Mass of evaporated water (kg)
n_o	Number of pool occupants
NPV	Net present value (€)
$P_{a,\ Tamb}$	Partial pressure of water vapour (kPa)
PBT	Payback time (year)
$P_{s,Tw}$	Saturation pressure of water vapour (kPa)
q	Linea Power exchanged (W/m)
Q_e	Latent load of evaporation from the pool (kWh)
T	Temperature (°C)

Greek symbols

α	Thermal diffusivity (m^2/s)
ρ	Density (kg/m^3)
ϕ	Humidity

Subscripts

amb	Ambient condition
bh	Bottom hole
conn	Connection at electricity network
D	Drilling
HP	Heat pump
P	Probe
Plant	Plant cost
w	Water
W	Workmen

in industrial plants, upon re-injection in the subsurface. Heat can be extracted at different rates, but to guarantee a sustainable use of geothermal energy, the rate of consumption should not exceed the rate of generation, so that the heat removed from the source is replaced on a comparable time scale. Geothermal energy plants develop below a certain level of energy production and typically provides base-load power, because they are generally immune from weather and seasonal variations, therefore producing energy almost constantly, in contrast to several other renewable technologies (e.g., based on solar and wind power) that produce time-varying power or heat.

Low-enthalpy geothermal plants do not require special environmental conditions and use the subsoil as a heat storage. Heat is transferred on the surface during wintertime, whereas excess heat in the buildings is given to the ground during summertime. Therefore, this technology exploits the constant temperature that the ground has throughout the year and allows the direct use of heat by using geothermal heat pumps (or ground source heat pumps, GSHP), in which the refrigerant fluid exchanges heat with the ground. Normally, at a depth of 1 m, it is possible to have a temperature around 10–15 °C. At this point, the heat pump uses the heat difference between the ground and the outside to absorb heat from the ground and make it available. The higher is this difference the better the performances are. To make the plant more environmentally compatible and energy-efficient, it can be combined with a photovoltaic plant that will produce the energy needed to the heat pump. The same plant can be used to cool the buildings by working the heat pump with an inverse process. Manzella [7] and Demirbas et al. [8] described all possible applications of geothermal technologies that use the heat from the ground other than the direct use, and which include electricity generation, space heating, greenhouse heating, and industrial usage. In particular, Demirbas et al. [8] describe the potential for geothermal energy in the Kingdom of Saudi Arabia, where some refreshment and swimming pools are already constructed.

Heating of swimming pools constitutes an energy-consuming procedure. The continuously rising prices of fossil fuels increased swimming pools' heating costs. This fact, combined with the economic crisis, led most of the swimming pools in Southern Europe to close. The high energy consumption in swimming pools presents an attractive challenge but also significant opportunities for energy conversion and improved indoor conditions [9–14]. Typically, in swimming pools, the energy consumption is 45% made from ventilation of the pool hall, 33% pool water heating, 10% heating and ventilation systems for the remainder of the building, 9% electricity for power equipment and lighting and 3% hot water services [1]. Many studies about heating of swimming pools using alternative passive or active heating technologies have been provided in previous articles.

Fig. 1. Swimming pool model.

Table 1
Climate data.

Variable	Value
Site	Agnano – Italy
Altitude	74 a.s.l.
Latitude	40.8539°
Degree days	1269
Climate zone	C
Distance by the sea	< 40 km
Average wind speed	2.3 m/s
Winter external air temperature, $t_{air,w}$	+2 °C
Heating season	15 November–31 March
Summer external air temperature, $t_{air,h}$	+32 °C
External relative humidity	45%

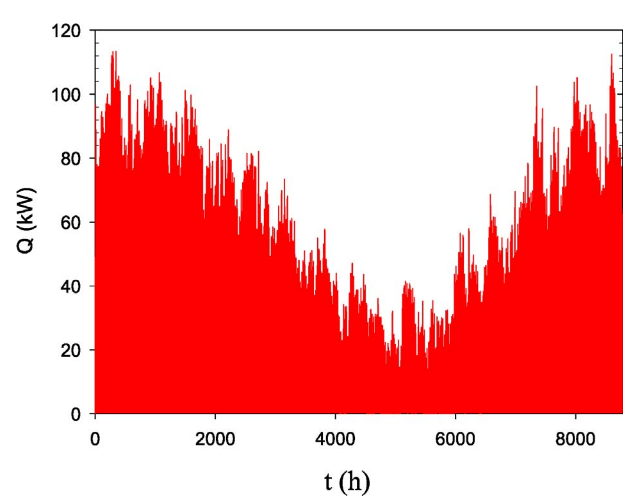

Fig. 2. Annual transmission loads profile per hour.