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Ground source heat pump technology use for heating and air-conditioning of a commercial/residential building

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This work presents an application of a ground source heat pump system (GSHP) for heating and air-conditioning of a commercial/residential building. The building itself is designed with high energy efficiency in mind, in compliance with Swiss „Minergie“ standard. Apart from the heat pump, building's systems include thermal solar collectors and seasonal heat storage. The emphasis of this work is on the design and hydraulic analysis of the ground-coupled heat exchanger. To enable future research on performance prediction and sizing of such exchangers, a sensor array was designed to monitor ground temperature and moisture in different areas, as well as perform different climatological measurements (insulation, air humidity, wind direction and speed).

1. Introduction

The interest in ground coupled heat pumps use for housing heating and cooling applications has grown since the 1970s as a result of the large increase in energy prices. Its main advantage is that it utilises low temperature heat accumulated in the ground, which is available in all areas of the world, reported by Rybach (2001). The worldwide status in 2005 is 15384 MWt installed capacity and 87503 TJ/y energy produced with scenario for growth in direct use of GHP for 2050 year is 750 000 MWt installed capacity and > 4 billions TJ/y energy produced, Ragnarsson (2009).
This work describes a phase of a project to design a ground heat pump system used in commercial – residential building in Osijek (Figure 1). One part of the building, with total area of 1452 m^2, will be built in accordance to Swiss Minergie standard.

2. Theoretical background

Ground, with its substantial heat capacity, represents excellent heat storage. This property enables it to be used either as an excess heat sink (cooling), or as a stored heat source (heating). Also, the large heat capacity means that ground temperature oscillations are much smaller than those of the surrounding air. So, at a large enough depth, the ground temperature is almost constant throughout the year, at around 10°C.

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Figure 1. A simulated image of a residential-commercial building in Osijek area

This means that in certain applications, so called “passive cooling” can be used, since this temperature is low enough. However, in heating applications, use of a heat pump is necessary to raise the stored heat’s temperature to a level required for the building’s heating system operation.

In this work, only the part of the design that concerns heat pump system with its ground-coupled heat exchanger will be presented. The design of such systems, once the building's heating and cooling demands have been determined, generally consists of these steps: choosing the appropriate heat pump type, determining the available surface for ground loop, determining soil properties and ground annual temperature depth profiles and ground heat exchanger design configuration choice and sizing, according to heat pump system's requirements and soil properties.

2.1 Heat pump

Choice of an appropriate heat pump is made considering the building'a heating and cooling demand. The performance of different systems can be compared through two efficiency indicators, COP (coefficient of performance) for heating, and EER (energy efficiency ratio) for cooling was confirmed by Shonder, 2002.

$$COP = \frac{Qcond}{Wel} = \frac{T}{T - T_0} \tag{1}$$

$$EER = \frac{Qevap}{Wel} = \frac{T_0}{T - T_0} \tag{2}$$

In COP equation, Q_{cond} is the useful heat supplied by the condenser and W_{el} is the work consumed by the compressor. Recent systems are able to achieve COPs well over 4, depending on operating conditions. The EER is calculated by dividing the cooling capacity of the unit by the power input at a given set of rating conditions.

2.2 Ground properties

Grounds annual depth heat profile is a basis for a GHP system design. It depends on the soil type, moisture and the amount of solar radiation. Without real measured data at the given location, the temperature profiles can be assumed based on measurements on similar locations. In absence of any kind of data, Kusuda correlation can be used (Doherty et al, 2004; Hartmann and Juzi, 2003). It calculates the depth heat profile based on 3 parameters, average annual ground surface temperature, the amplitude of annual surface temperature change, and ground's thermal diffusivity. Estimated parameter's values are shown in Table 1.

$$T\left(x,t\right)=T_m-T_a\times e^{-x(\pi/365\alpha)^{0.5}}\times\cos\left(\frac{2\pi}{365}\left(t-t_{cd}-\frac{x}{2\sqrt{365/\pi\alpha}}\right)\right) \quad (3)$$

T_m : Annual average ground surface temperature, °C
T_a : Half of annual ground surface temperature amplitude, °C
x : Depth, m
α : Ground's heat diffusivity, m^2/day
t : Time of year, expressed in days from 1st of January.

Table 1: Estimated model parameters

T_m, °C	T_a, °C	α_s, m^2/day
10	12	0.058

2.3 Ground source heat exchanger design

Closed-loop systems, which is the type considered for this application, use underground plastic piping networks, which act as the earth-coupled heat exchangers. The most commonly used piping material is high-density polyethylene (HDPE). Heat exchangers configurations can be divided into two general categories, according to their orientation – horizontal and vertical. Horizontal heat exchangers represent a considerably smaller investment, but require relatively large surface for installation. During their design, a various number of factors must be taken into consideration: soil type, position and configuration of available ground for installation, influence of ground surface cover, and communal and other underground infrastructure. When the available installation surface is small, vertical heat exchangers, or so called ground probes are used. Here, the heat exchangers are placed in vertical wells drilled to depths of 50-200 m. They are more efficient, but also more expensive to install.

3. Application

3.1 GHP system sizing

The heat pump is sized based on the building's energy balance. According to the Minergie standard (total energy consumption to 42 kWh/m^2), the building's peak energy demand can be calculated as:

$$30 \text{ W} / \text{m}^2 \cdot 1452 \text{ m}^2 = 43.56 \text{ kW} \sim 44 \text{ kW}$$

The building's design includes low-temperature floor heating during heating season (35°C), warm water heating all year round (65°C), and cooling during summer. These design temperatures together with minimum allowable ground loop temperature to avoid freezing, govern the sizing of a heat pump unit itself. Considering all this, Vitocal 300 BW254 heat pump was chosen. Its characteristics, are shown in Table 2. The available surface for ground loop is shown in Figure 2. It can be seen that the available ground surface was relatively small (400 m^2).

With approximately 40W/ m of probe depth, a single 215 m deep double U pipe probe, would supply approximately 8.6 kW. Since this application was meant to be an experimental facility for GHP application research, the following combination was proposed. 5 vertical probes, 215 m deep, which supply 43 kW altogether, and 5 parallel trenches of slinky horizontal heat exchanger, which supplies approximately 10 kW.

These two circuits give a total of 53 kW of heat extraction, or so called cooling capacity. The designed configuration is shown in Figure 3, and the systems characteristics are given in Table 3.

Table 2. BW 254 specifications (www.viesmann.co.uk)

Operating point (B-brine, W-water)	[°C]	B0 / W35	B2 / W45	B2 / W55
Rated heating output	[kW]	55.6	57.8	55.8
Cooling capacity (ground)	[kW]	42.7	41.3	36.6
Power consumption	[kW]	12.9	16.5	19.2
COP		4.3	3.5	2.9

Heating water circuit		
Required water flow	[l /h]	4600
Condenser pressure drop	[mbar]	120
Maximum output temperature	[°C]	55
Brine circuit		
Breine flowa	[l /h]	12600
Evaporator pressure drop	[mbar]	310
Maximum input temperature	[°C]	25
Minimum input temperature	[°C]	-5
Ethylene glycol volume percentage – horisontal heat ex.	[vol%]	33
Ethylene glycol volume percentage – vertical probe.	[vol%]	23

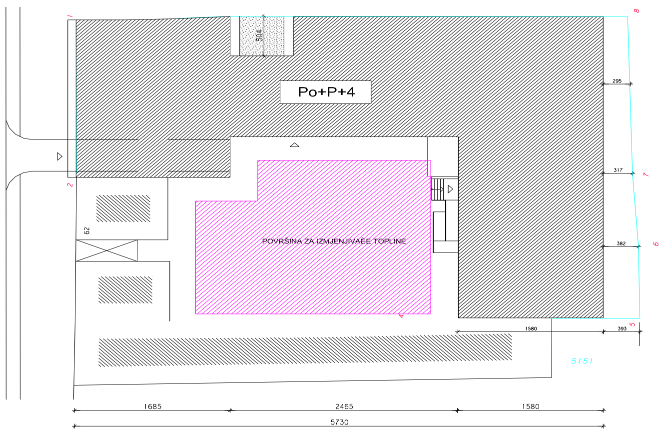

Figure 2. Available installation surface

3.2 Measurements

Since there are no relevant data concerning ground temperatures at greater depths, this study proposes continuous measurements of ground properties to depths of approximately 20 m. Temperature and moisture sensors will be placed at every 25 cm, which gives a total of 80 sensor pairs. Figure 4 shows designed temperature and moisture sensors locations around horizontal exchangers, recommended by Sesartic et al., 2007.

Table 3. Ground loop specifications

Probe type	double U pipe
Pipe specification	PE 32 x 2,9 mm, PN 10
Probe depth	215 m
Specific cooling capacity	40 W/m
Total cooling capacity per probe	8,6 kW
Brine flow	2283.3 l/ h (1141.65 l/h per pipe)
Horisontal exchanger configuration	Slinky, 5 parallel trenches
Pipe specification	PE 25 x 2.3 mm, PN 10
Pipe length per trench	158 m
Total cooling capacity	10 kW
Brine flow per pipe	380 l 7 h

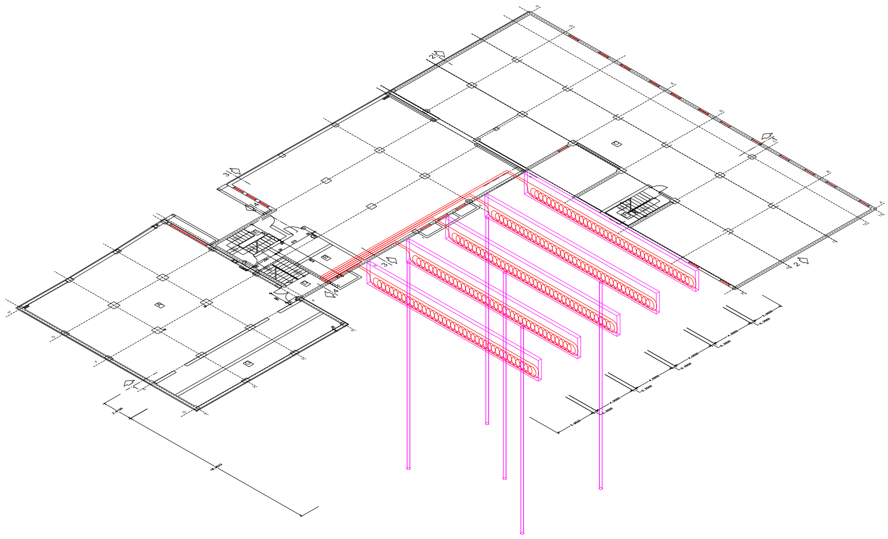

Figure 3. Designed ground loop configuration

Black dot in the middle denotes exchanger location. Brine flow, temperature and pressure will also be continuously monitored at inlet and outlet of exchangers and probes.

4. Conclusions

This work presents the geothermal heat pump (GHP) application in a residential – commercial building in Osijek. GHP will be the buildings main heat source for both, space and water heating. However, since the building will use a reversible cycle GHP, it will also be used for cooling during the cooling season. This work is focused mainly on the design and sizing of the ground-coupled heat exchanger.

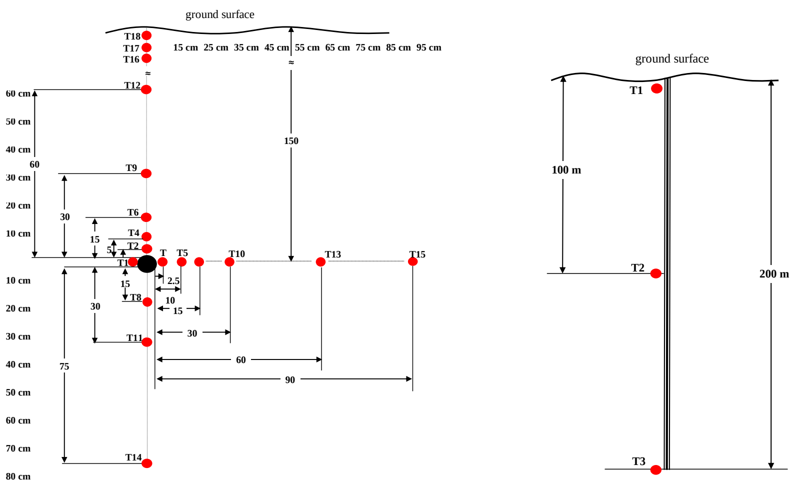

Figure 4. Temperature and moisture sensors locations around horizontal exchangers and vertical probes

The system sizing was made based on the building's energy demand (for space and warm water heating), which is set by the Minergie standard. Based on the energy balance, it was found that 6 vertical probes would satisfy the required cooling capacity. However, since this building will be an experimental facility for the research of GHP application in Croatian climatic conditions, one probe will be substituted by a horizontal heat exchanger in order to gain an experimental insight into its operation. For this reason, various soil properties, as well as operating conditions will be continuously measured and monitored.

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