# Direct Ground Cooling: Influence of Ground Properties on the Ground Heat Exchanger Size

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## ABSTRACT

In this paper the thermal behaviour of a direct ground cooling system located in Milano, Italy, is studied by means of dynamic simulations performed in the TRNSYS environment. The simulation model consists of a reference building equipped with radiant panels connected to a vertical ground heat exchanger. Room thermostats and chilled surface condensation sensors provide system control. The ground heat exchanger size is adjusted in order to provide summer comfort conditions in the building as well as sustainable operation over a long period. The effects of ground thermal properties on the system performance and sizing are investigated. Specific injected energy values (thermal energy per year per unit length of the ground pipes) are found and discussed.

## KEYWORDS

Cooling, ground, thermal properties, design.

## INTRODUCTION

Ground coupled heat pumps for heating and cooling of buildings are getting more and more popular, due to their high coefficient of performance [1]. In water-to-water systems the heat pump operates between a ground loop, containing a ground heat exchanger, and a building loop, containing radiant panels. However in favourable climate and ground conditions, cooling can also be achieved by circulating water directly between the ground heat exchanger and the radiant panels. This direct ground cooling option is attractive because of its lower energy consumption [2].

The ground heat exchanger design is a critical issue for all ground coupled systems. Under sizing can compromise the system performance, while over sizing has a strong impact on the system first cost. Available design methods and guidelines mainly refer to heat pump systems and usually consider heating applications [3, 4]. A specific heat extraction rate or energy, that is thermal power or energy per unit length of the heat exchanger, is generally adopted as a sizing parameter [5]. Ground thermal properties may have significant influence on this key parameter [4]. They are usually estimated on the basis of the ground composition, although they strongly depend on water content and porosity [3, 6]. For large scale applications, it may be worthwhile to measure the ground thermal conductivity on site by performing a thermal response test [7]. Design criteria for direct ground cooling systems are lacking [8], as well as knowledge about the influence of the ground thermal characteristics on their performance. In this paper dynamic simulation is used to size the U-pipe heat exchanger of a direct ground cooling system for a reference building, as a function of the ground thermal properties. The thermal energy injected per unit length is found and discussed.

## REFERENCE SYSTEM

The model system is a two storey residential building equipped with radiant floors connected to a vertical ground heat exchanger. The building has a total surface of about 100 $m^2$ and is located in Milano, in the Northern part of Italy. Typical residential gains due to occupants and equipment are considered. Chilled floors are made of plastic pipes (outside diameter 1.7 cm, pipe-to-pipe spacing 10 cm) in a concrete slab, with backside insulation. The ground heat exchanger is made of a polyethilene U-pipe inserted in a borehole backfilled with grout (borehole diameter 12 cm; U-pipe outside/inside diameter 3.2/2.6 cm; grout thermal conductivity 1.5 W/(mK)). Water circulates in the closed loop by means of a pump. Three thermal zones can be identified in the building. Each one is provided with a room thermostat and a dew point sensor on the floor. Every zone system is switched off whenever the air temperature in the zone is below $T_{set}$=24.5°C or a condensation risk on the chilled floor is detected. The system layout is shown in Figure 1.

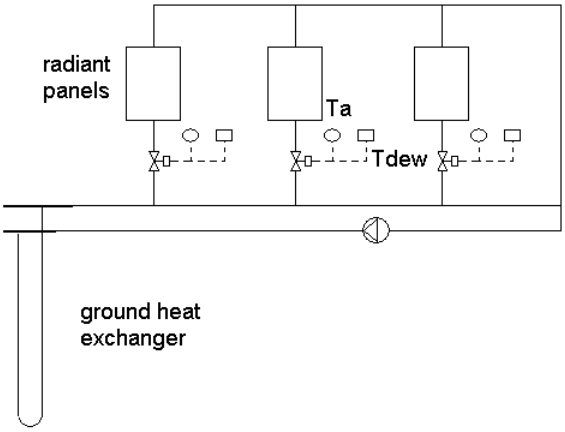

Figure 1 : direct ground cooling system layout

## SIMULATION TOOL

The building and the direct ground cooling system are modelled using the well known dynamic simulation software TRNSYS 16 [9]. Within TRNSYS every component is described by a specific routine, called “type”, that can be either a standard or a user-written one. Types are then linked together. The standard Type 56 Multizone Building Model is used here for the building. Radiant panels are simulated as “active layers” within the Type 56. The ground heat exchanger is modelled through the TRNVDSTP non standard type [10]. This type calculates the heat transfer between the fluid in the pipes and the surrounding ground, as well as the conduction in the ground. The climatic influence of the outside air wave is taken into account as a boundary condition at the ground surface. The temperature increase with depth due to the geothermal flux is described through a thermal gradient. For Milano an average surface temperature of 11.8°C, corresponding to the annual mean air temperature, and a geothermal gradient of 0.02 °C/m are chosen. Weather data are taken from a Milano typical meteorological year.

## METHODOLOGY

The U-pipe depth in the ground H is the sizing parameter. In order to assess the proper H for each type of ground, the direct ground cooling system operation and its effects on the comfort conditions in the building are simulated. The cooling system is assumed to work for the whole summer, from June to August. Since a sustainable design should take into account the effects of heat injection into the ground year after year, the system is simulated for a time period of 30 years. No winter use of the ground heat exchanger by means of a heat pump is assumed, so that sustainable operation is based only on the natural recharge of the ground.

The following methodology is proposed to measure the comfort conditions on a summer scale and to size the ground heat exchanger. At every simulation time step the Predicted Mean Vote (PMV) is calculated from the simulation outputs. Then a mean value <PMV> and a mean standard deviation $\Delta$ over the summer period are calculated. According to the international standard ISO 7730 [11], a “class B” thermal environment corresponds to the condition $|\mathrm{PMV}| \leq 0.5$ or PPD ≤ 10%. Then the ground heat exchanger length H is adjusted in order to reach, throughout the 30 years period, the following condition:

$$\langle \mathrm{PMV} \rangle + \Delta \leq 0.5 \qquad (1)$$

According to literature [3, 6, 12, 13], for a given rock or soil type a range of values for thermal conductivity $k_g$ and capacity $C_g$ are found. Beside the ground composition and physical structure, these properties are affected by its porosity and water content. Consequently, knowing the ground type limits very little the thermal properties. In this study seven representative ground types, identified by as many pairs of thermal properties ($k_g$, $C_g$), are used. The ground types are listed in Table 1 together with other relevant thermal properties, namely the diffusivity $\alpha_g$ and the admittance $(k_g C_g)^{1/2}$.

TABLE 1
Ground types and properties
(thermal conductivity $k_g$, volumetric capacity $C_g$, diffusivity $\alpha_g$, admittance $(k_g C_g)^{1/2}$)

| Ground type | $k_g$ [W/(mK)] | $C_g$ [MJ/m$^3$K] | $\alpha_g$ [m$^2$/s] | $(k_g C_g)^{1/2}$ [Ws$^{1/2}$/(m$^2$K)] |
|---|---|---|---|---|
| 1 | 0.5 | 1 | $5.0 \cdot 10^{-7}$ | 707 |
| 2 | 0.5 | 1.5 | $3.3 \cdot 10^{-7}$ | 866 |
| 3 | 1 | 2 | $5.0 \cdot 10^{-7}$ | 1414 |
| 4 | 1 | 3 | $3.3 \cdot 10^{-7}$ | 1732 |
| 5 | 2 | 2 | $1.0 \cdot 10^{-6}$ | 2000 |
| 6 | 2 | 3 | $6.7 \cdot 10^{-7}$ | 2449 |
| 7 | 3 | 2 | $1.5 \cdot 10^{-6}$ | 2449 |

## SIMULATION RESULTS AND DISCUSSION

For every ground type, simulation outputs can be summarized by a graph showing the <PMV> versus the U-pipe length H. Figure 2 shows this behaviour for ground type 1 at the 1st summer of operation. Bars around <PMV> represent ± Δ. At H=0 the <PMV> gives the free-floating condition in the building. The total energy injected into the ground in the whole summer E is also plotted.

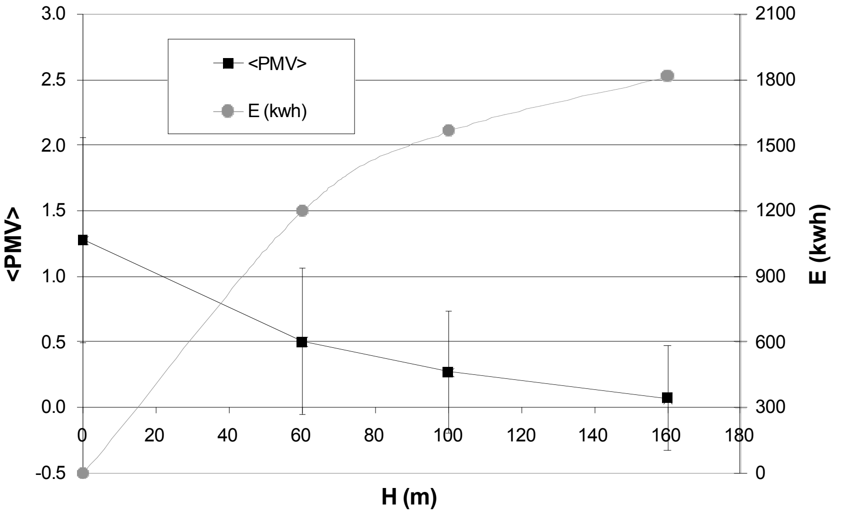

Figure 2 : <PMV> and total energy injected E versus ground heat echanger length H at the 1st summer of operation for ground type 1.

Then for every ground type a proper heat exchanger length, satisfying the condition expressed in Eqn.1, is found and reported in Table 2. The comparison between comfort conditions at the 1st and at the 30th year of operation, also available in Table 2, shows a substantial stability of the direct ground cooling systems performance. This result is analogous to the one obtained by other authors [14] for a single borehole used to extract heat from the ground with a heat pump. Sustainable operation may be expected as long as the ground heat exchanger is made of a single or a few boreholes, with no or little thermal interaction among neighbour boreholes. Table 2 shows that ground thermal properties strongly influence the ground heat exchanger size: in case of ground type 1 the required length is 4 times the one required for ground type 7.

TABLE 2
Ground heat exchanger size and comfort index for different ground types

| Ground type | Ground heat exchanger length H (m) | <PMV> ± Δ at 1st year | <PMV> ± Δ at 30th year |
|---|---|---|---|
| 1 | 160 | 0.07 ± 0.37 | 0.09 ± 0.39 |
| 2 | 150 | 0.07 ± 0.37 | 0.08 ± 0.39 |
| 3 | 80 | 0.07 ± 0.37 | 0.09 ± 0.38 |
| 4 | 80 | 0.06 ± 0.37 | 0.07 ± 0.38 |
| 5 | 60 | 0.06 ± 0.37 | 0.06 ± 0.37 |
| 6 | 50 | 0.04 ± 0.36 | 0.04 ± 0.36 |
| 7 | 40 | 0.08 ± 0.37 | 0.08 ± 0.38 |

The importance of thermal properties may also be studied by setting the ground heat exchanger size and by comparing its performance in different grounds. As already mentioned, the thermal power or the thermal energy per unit length are generally used as performance parameters for ground coupled heat pumps [4, 5]. Then in this study the thermal energy injected into the ground in a summer per unit length E/H is calculated. However, as shown in one case in Figure 2, E is not a linear function of H, since the temperature difference between the water and the ground decreases with depth. Consequently E/H represents an average value over H that varies with H. Here E/H is calculated for H=60m and H=100m and is plotted as a function of thermal conductivity $k_g$ (in Figure 3) and thermal admittance $(k_gC_g)^{1/2}$ (in Figure 4).

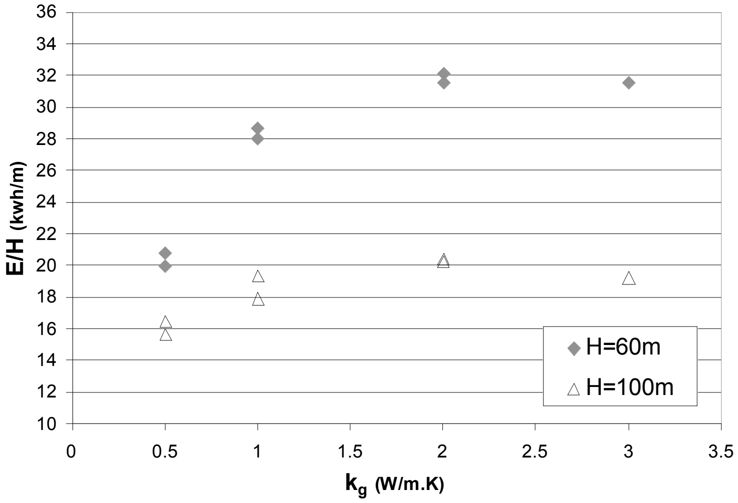

Figure 3 : Specific injected energy per year E/H vs ground conductivity $k_g$.

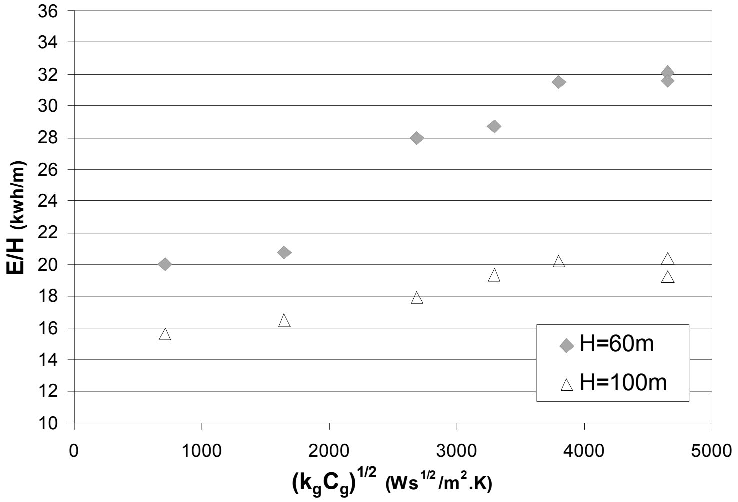

Figure 4 : Specific injected energy per year E/H vs ground thermal admittance $(k_gC_g)^{1/2}$.

A qualitative comparison between the E/H values found here and the ones obtained by other authors [8] can be carried out. They report an E/H ranging from 20 to 40 kwh/m per year, but assume that a heat pump operates in winter with the same ground heat exchanger, enhancing the summer performance. A qualitative comparison with E/H values characteristic of ground source heat pumps used for winter heating [4] shows that direct ground cooling system performance is generally lower.

## CONCLUSIONS

In this paper the impact of ground thermal properties on the performance and size of a small scale direct ground cooling system is investigated. The results show that the system operation is very sensitive to the ground thermal conductivity and its thermal admittance. This means that a good knowledge of the underground properties is fundamental.

Beside ground thermal properties considered in this paper, groundwater flow may have a significant influence on the performance of a direct ground cooling system, as in general for all ground coupled heating and cooling systems. This issue will be addressed in a future study.

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