Low temperature applications of geothermal energy use

Daniel Pahud, Milton Generelli, Paolo kaehr, Dario Salvatori and Angelo Bernasconi, SUPSI – DACD – LEEE

Zusammenfassung

Es werden drei Forschungsprojekte vorgestellt, die geothermischen Anwendungen bei Niedrigtemperaturen behandeln. Eine Heizungs- und Kälteanlage, gekoppelt mit einer bedeutenden Anzahl Erdwärmesonden, wurde durch kalibrierten numerischen Simulationen analisiert. Es wurden gewissen Empfehlungen formuliert.

Eine Machbarkeitsstudie bei einer Thermalbadzentrum hat bewiesen, dass mehr als die Hälfte des thermischen Energiebedarfs mit der geothermischen Wasserenergie gedeckt werden kann. Das Wasser wird aus dem Alptransit im Bodio entnommen. Die resultierende Energiekennzahl des Zentrums ist sehr klein.

Das letzte Projekt ist noch nicht fertig. Das Ziel ist die Erstellung eines Handbuch für die Planung, Umsetzung und Betrieb von energetischen Geostrukturen, die die unterirdische Wärme und Kälte auf niedrigen Tiefen nutzen. Das Handbuch wird in der Reihe der SIA-Dokumentationen vorhanden sein.

Résumé

Trois projets de recherches traitants d’applications géothermiques à basse température sont présentés. Un système de chauffage et de refroidissement couplé à un nombre important de sondes géothermiques est analysé par simulations numériques calibrées. Des recommandations sont formulées.

L’étude de faisabilité d’un centre thermal a montré que plus de la moitié de ses besoins en énergie thermique peuvent être couverts par l’énergie géothermique de l’eau qui sortira de la transversale Alpine à Bodio. L’indice énergétique résultant du centre est bas.

Le dernier projet n’est pas encore terminé. Il traite de la rédaction d’un guide pour la planification, la construction et l’exploitation de géostructures énergétiques exploitant la chaleur et le froid du sous-sol à faible profondeur. Le guide sera édité dans la série des documentations SIA.

Summary

Three research projects dealing with low temperature applications of geothermal energy use are presented. A heating and cooling system coupled to a large number of vertical borehole heat exchangers is analysed by calibrated numerical system simulations. Simple design guidelines are formulated.

The feasibility study of a spa at Bodio has demonstrated that half of its thermal energy requirement can be covered by geothermal energy from the transalpine tunnel water. The resulting energy index of the spa is low.

The last project, still in progress, deals with the redaction of a guide for the design, construction and operation of heating and cooling systems using energy geostructures. The guide will be published in the series of the SIA documentations.

1. Introduction

Three research projects are presented in this paper. They all deal with applications that have a low temperature use of geothermal energy. They are :

- analysis by calibrated numerical system simulation of a heating and cooling system coupled to a large number of vertical borehole heat exchangers;
- elaboration of an energy concept for a spa with the objective of maximizing the potential of the geothermal energy of the water that will come out of the new transalpine tunnel at Bodio (TI);
- redaction of a guide for the design, construction and operation of heating and cooling systems using energy geostructures.

The first two projects are finished and the third is still in progress. It will conclude at the beginning of next year with the printing of a SIA document.

2. Heating and cooling with multiple borehole heat exchangers

An industrial building at Wollerau is built on 32 borehole heat exchangers. They are 135 meters long each and positioned on three lines with a spacing of about 8 meters. They are coupled to a 190 kW_{th} heat pump that can also operate in a reversible mode and provide 210 kW_{th} cooling. Apart from an emergency gas burner of 190 kW_{th}, the system provides quasi the totality of the heating and cooling requirements, estimated to respectively 350 and 85 MWh/year in the design phase.

The ground coupled system was measured for two years from 1996 to 1998 [1]. Using these measurements, a dynamic simulation model of the heating and cooling system has been developed and calibrated. On the basis of TRNSYS [2] and some non-standard components (e.g.: TRNSBM [3], used for the simulation of multiple borehole heat exchangers), the real system has been reproduced [4]. It has the advantage of taking into account the electric energy of the circulation pumps. The global efficiency of the system, defined by the ratio between the sum of the delivered annual heating and cooling energies by the total annual electric energy used to run the system, is established, in this case, to 3.3.

The main objective of this study was to extend the practical experience gained by the measurement campaign. Analyses of the system's thermal behaviour and sensitivity analyses are only possible with system simulation. They are often the basis of guidelines for system sizing.

Sizing problematic

Multi-disciplinary information has to be collected and estimated during the design process. It has to cover the local geology and hydrogeology conditions, the thermal energy requirements that the system will have to cover, the integration of the ground coupled system in the energy concept of the building and so on. Last but not least, the problematic of the connecting pipes' insulation between the boreholes has to be addressed when they are located under the building's basement. All these aspects have to be considered for the sizing of the heat pump, the cooling machine if required and the number, length and position of the borehole heat exchangers.

The fluid temperature in the borehole flow circuit can only vary between given temperature limits. They have to be respected for both **short time effects** (this mainly conditions the total borehole length relative to the size of the heat pump and the cooling machine) and **long term effects** (for a given borehole configuration and without a significant movement of ground water flow, this mainly determines the annual ratio of injected over extracted thermal energy from the boreholes.

The minimum and maximum fluid temperatures depend on technical or practical criteria. In the case of borehole heat exchangers under a building, the heat carrier fluid temperature must not drop below 0°C. For the maximum fluid temperature, as long as it remains below 25 – 30 °C, no particular problems are to be expected. In the case of direct cooling[1], the maximum fluid temperature depends directly on the maximum temperature level in the cooling distribution.

The difficulty of system sizing is to find an optimal sizing that is not too close to the permissible limit. It is thus important to keep some margin in the sizing, so that a change in operational conditions or design parameters does not have a critical influence on system operation. System simulation provides once again valuable information.

Two types of design parameters

With the help of sensitivity analyses, two parameter categories have been identified: parameters associated with the system **integration** and parameters associated with its **sizing**.

The **integration parameters** have a significant influence on the system performance indexes, and in particular on the global system efficiency. They determine primarily the integration of the system and the borehole heat exchangers in the energy concept of the building. Heating with the lowest fluid temperature in the heat distribution and cooling with the highest possible are the result of an optimal system integration. It is greatly facilitated if the Minergie standard is applied. A building design that permits heating and cooling with active concrete plates results in an optimal system integration. A global system efficiency greater than 5 has been simulated. As direct cooling is normally characterised by a weak but constant cooling power, it combines perfectly with active concrete plates. Their large heat capacity helps to solve the discrepancy between cooling offer and cooling need. A simpler system is also possible, as a cooling machine may not be required in the ground coupled system.

The **sizing parameters** primarily determine the technical feasibility and the long term viability of the system. They have to guarantee that the heat carrier fluid temperature in the borehole heat exchangers always remains within the fixed limits. Unlike integration parameters, they have only a slight influence on the system performance indexes. The length of the borehole heat exchangers and the ground thermal conductivity, varied from -30% to +30% around their design value, have a small influence on the global system efficiency. However these parameters have a strong influence on the minimum and maximum heat carrier fluid temperature in the boreholes, either on the short term (due to the dynamic evolution of the system) or long term effects (after the mean annual ground temperature in the borehole zone has stabilised).

Main results

Some guidelines have been established on the basis of an ideal system integration. For the borehole configuration of the studied system (32 boreholes on three lines with an average spacing of 8m) and the local ground conditions (no ground water flow and ground thermal conductivity of 2.3 W/(mK)), sizing parameters for the boreholes are:

- heat extraction per meter borehole: **40 W/m**
- annual thermal energy extracted per meter borehole: **60 kWh/m/year**

[1] Direct cooling is cooling without a cooling machine, by connecting the borehole flow circuit to the cooling distribution via a heat exchanger

This sizing is only possible if at least **20 kWh/m/year** is injected back into the boreholes. It can be realised by direct cooling without the use of a cooling machine. However direct cooling is very sensitive to the temperature level in the cold distribution and a “high temperature” cooling distribution is necessary. A forward fluid temperature of 22°C is assumed in the cold distribution. The **direct cooling solution** can handle an increase of the cooling demand until the ratio of the annual energies “injected over extracted” reaches 0.7. The specific injection values are:

▪ heat injection per meter borehole:	**peak**	**40 - 50 W/m**
	average	**10 – 13 W/m**
▪ annual thermal energy injected per meter borehole:		**20 – 35 kWh/m/year**

With a ratio “injected over extracted” greater than 0.7, a cooling machine is required if the totality of the cooling demand is to be met. The direct cooling mode is dominant as long as the ratio remains below 0.9. A greater ratio leads to an increase of the mean ground temperature in the borehole zone and the direct cooling mode decreases over the years. In figure 1, the feasibility of direct cooling with or without a cooling machine is shown in function to the ratio of the annual cooling and heating demands, and the mean heat pump performance coefficient.

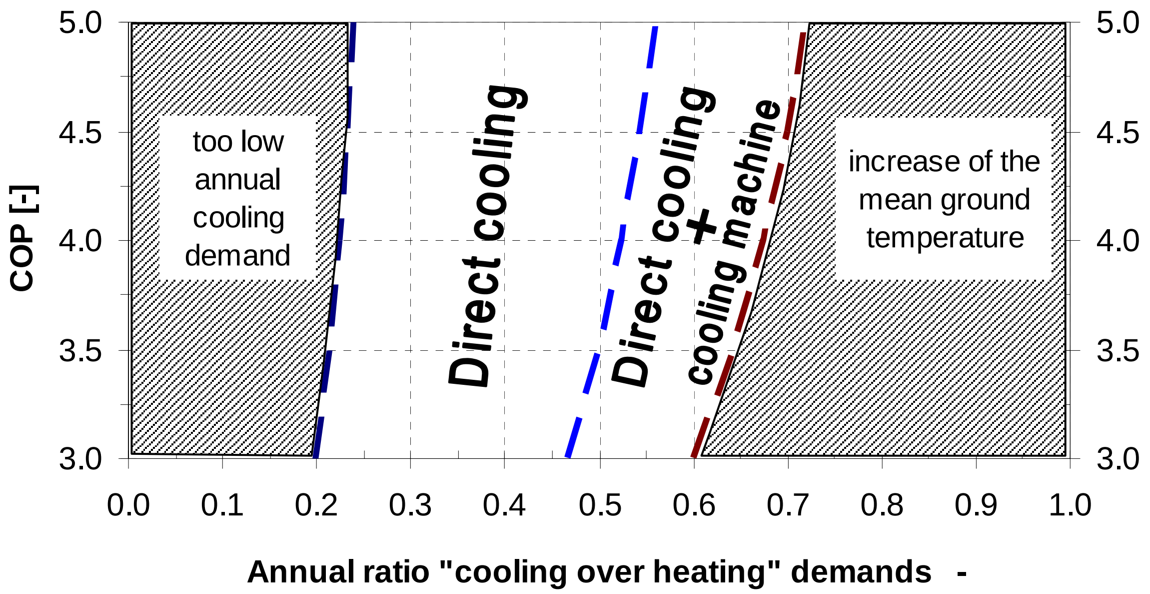

Figure 1: Direct cooling feasibility in function to the annual ratio of cooling over heating energy demands and the mean heat pump performance coefficient (COP)

If recommendations and rules of thumb are important to establish an early energy concept, it is also important to have the possibility of using a dynamic simulation tool. The problematic related to the project, the evaluation of various variants and their validation, and finally the improvement of the system sizing for a safe operation can all be addressed with a dynamic system simulation tool. That which has been developed has been documented and can easily be adapted to meet the requirements of a new project.

3. Geothermal energy from tunnel water for a spa

The north – south alpine transversal tunnel will have its south exit in the immediate vicinity of the Bodio village. The 58 km long tunnel will have a drainage effect on the Gotthard mountain range. More than half of the drained water will exit through the south gate. Due to the important rock layer that covers the tunnel (up to 3 km), the water will come out with a temperature comprised between 20 and 35 °C [5]. Having a constant flow estimated to 200 litres/s, this water represent an important geothermal resource. Cooling down this water by 10 K provides a thermal power of about 8 MW. For ecological reasons, the water has to be cooled down before being released in the river Ticino.

The three communes of Bodio, Giornico and Personico have decided to initiate a study aimed to evaluate the technical feasibility of a spa. It would be built on existing ground in Bodio, which is occupied at the moment by an old workshop. The site position is at the same time close to the south gate of the tunnel and easy to reach with transportation. The LEEE carried out the study with the objective to develop and assess a low energy concept that would maximize the potential of the local geothermal resource [6].

Architectural concept

In relation to the ground area at disposition (2'400 m^2) and the requirements of a modern spa, a reference building has been defined. Although it has to be considered as an indication for the definitive project, it serves as a basis for the energy analysis. The two main ideas are to reuse the existing building volume (for edification regulation reasons) and bring the usable spaces up to the first floor. It limits vision from outside and leaves the ground floor free for the technical installations.

The spa will have a volume of 6'000 m^3 and a usable area of 2'000 m^2. It will offer a 30 °C swimming pool, a 36 °C wellness pool, a 36 °C Turkish bath and saunas for about 60 to 70 people (see illustrations in figure 2).

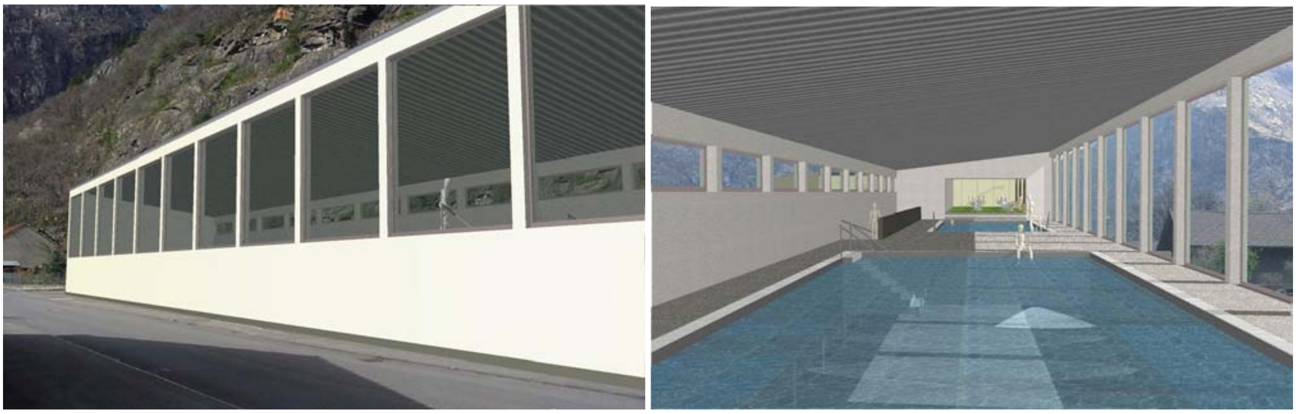

Figure 2: Views of the spa in Bodio (TI)

Energy concept

The Minergie standard definition for a covered swimming pool is applied. It requires that the annual heating demand, assessed under standard conditions, does not exceed 120 MJ/(m^2y). A value of

90 MJ/(m^2y) is calculated[2] (U-values of 0.2 W/(m^2K) for the walls, 1.3 W/(m^2K) for the windows, 0.15 W/(m^2K) for the roof, etc. [6]). At least 20% of the annual hot water demand has to be covered by renewable energy, which will in this case be fulfilled by geothermal energy.

The particular problematic of a spa has been carefully studied. Special attention has been placed on the fresh water demand for the pools and the showers. The evaporation rate of the pools has been assessed for typical situations [7]. These aspects conditioned various choices in the energy concept.

The spa would use about 13'000 m^3 of fresh water per year (about 35 m^3 per day) for the baths and showers. As tunnel water comes solely from the mountain (it is not mixed with water coming from the train tracks), a direct use can be considered. It will save water and also energy. In this study, a conservative temperature of 20 °C is assigned to geothermal water, which is equivalent to a geothermal pre-heating of the fresh water that raises its temperature by about 10 K.

Due to the high temperature of the baths, the important level of water evaporation conditions the size of the ventilation system. Its first task is dehumidification. The layout is based on Kannewisher [8] and involves a heat recovery unit as a central element. A cooling unit is also integrated to take over dehumidification when the absolute humidity of the outside air is too high (at Bodio, it is greater than 9 g/kg during about 3 months per year).

Spa heat balance

With the actual indoor air temperature (30°C) and the required air change rate (without taking into account heat recovery), the spa heating requirement is calculated to 550 MJ/(m^2a). However it represents only one third of the total thermal energy requirement of the spa, which is estimated to 1'200 MWh/year. Another third is required to compensate for the pools' evaporation losses. Nearly a quarter is used to heat fresh water for the pools, which is necessary to maintain water quality (see figure 3).

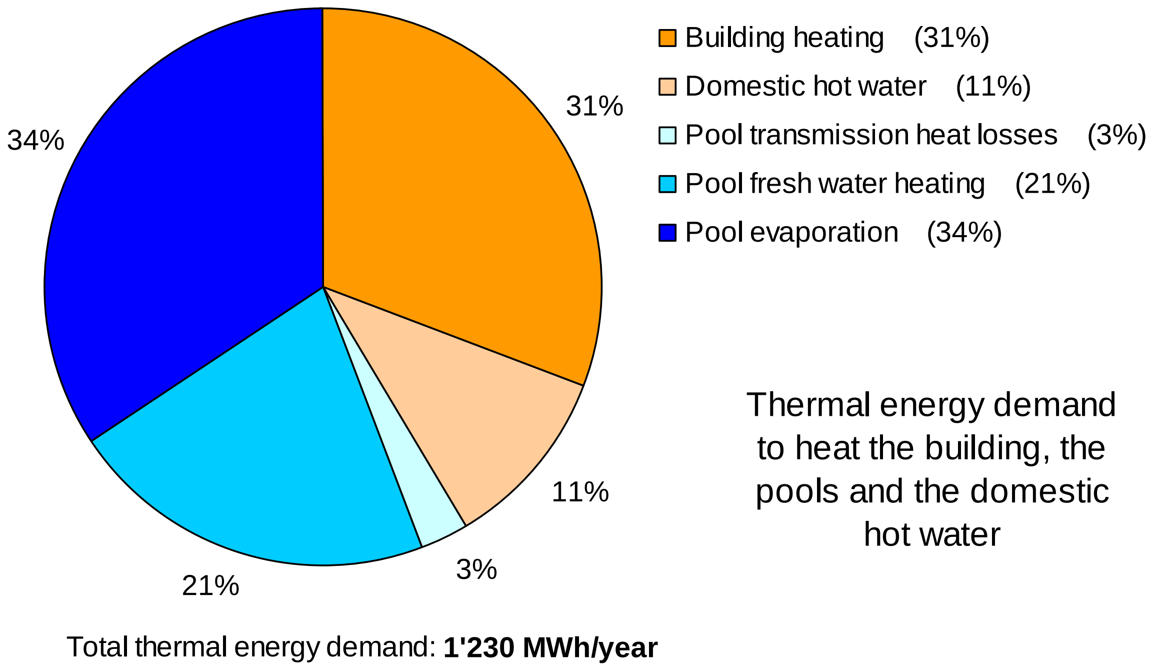

Figure 3: Thermal energy requirement of the spa

[2] The area unit refers to the heated area corrected with the room height factor. It is calculated to 2'500 m^2

The total thermal energy demand is primarily covered by a heat pump that extracts heat from the tunnel water (56%). The heat recovery unit of the ventilation system, having a mean annual efficiency of 75%, contributes 22%. Direct use of the mountain water from the tunnel provides another 11%. Waste heat from the dehumidification cooling unit can be used to heat the pools and contribute 6%. The remaining 5% are covered by an auxiliary burner used for peak power loads and to raise the hot water temperature from 40 to 60 °C.

Geothermal energy from tunnel water contributes globally for more than half of the total thermal energy requirements (55%).

Final energy for the technical installations is estimated to 410 MWh/year. Fossil energy used by the auxiliary burner amounts to 18%, whereas the remaining 82% are divided between electricity for the heat pump (38%), electricity for pool filtering pumps (25%), electricity for the ventilation system fans (14%) and electricity for the cooling unit (5%). The corresponding energy index is calculated to 600 MJ/(m^2year). Taking into account electricity for other uses (illumination, saunas, etc.), the global energy index for the final energy is estimated to **700 – 800 MJ/(m^2year)**. This index is far below the target value of 1'100 MJ/(m^2year), which is recommended for a similar centre of small size [8]. Without tunnel water and the heat pump, the global energy index would rise to about 2'000 MJ/(m^2year) if the auxiliary burner has to cover the difference.

The use of geothermal energy has proved to be technically feasible. If the project is carried out, the study will serve as a basis for the thermal quality of the building envelope and the energy concept of the spa.

4. Energy geostructure: a guide for system design, construction and operation

An energy geostructure is a structure in contact with the ground that is equipped with pipes to transfer heat for heating or cooling purposes. An energy geostructure is an application that enables use of shallow geothermal energy. The most common type of energy geostructure is energy piles. In figure 4 the metallic reinforcement of a cast-in-place foundation pile equipped with pipes is shown.

Figure 4: Pipes fixed on the metallic reinforcement of a cast in place foundation pile

The project has as objective the redaction of a guide for the design, construction and operation of energy geostructures. The guide will be comprised of about 80 pages and will be edited as a SIA document. It is planned to produce two versions of the document, one in French and one in German.

The document will synthesise a wide range of research results and practical experience covering the last 10 years. No less than 10 authors are contributing their own experience to the document. It will contain 13 chapters and 7 annexes covering geological, conceptual, design, energy, static, technical, practical, economical, ambient and legislative aspects. Documented examples are also presented. It will be aimed at energy designers, architects, HVAC[3] engineers, civil engineers, geologists, contractors and associations or people interested in energy geostructures.

It is planned to edit the document at the beginning of 2005.

5. Literatur/Referenzen

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[3] HVAC : heating, ventilation and air conditioning