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Heating and cooling systems with heat exchanger piles

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Abstract

A heat exchanger pile is a pile foundation equipped with a channel system, so that a heat carrier fluid can be circulated in order to exchange heat with the surrounding ground. A set of heat exchanger piles, usually coupled with a heat pump, can be used for heating and/or cooling purposes. The advantage of such a system is its ability to use the energy of the environment without too high costs; it is thus in perfect accordance with the philosophy of a sustainable development.

A dynamic simulation model based on TRNSYS is developed which shows good concordance with experimental data. A sensitivity analysis is performed with this model, which enlighten the importance of parameters like the thermal ground conductivity and the ground water flow velocity. Some recommendations concerning the design of such a system are finally given.

Introduction

In the context of environmental problem such as the global warming, everyone must try to better use the primary energy resources. One way is to promote heat pumps (HP) for buildings heating and cooling which allows the use of the energy of the environment (air, water or ground). In the case of the HP with air, the efficiency of such system is the lowest right when the heat demand is the greatest; HP with water will suppress this problem, but lakes or rivers are not everywhere available. Remains the HP systems using the heat of the ground as cold or hot sources. Up to now, the most common idea was to use boreholes, which are expensive. Then came the idea to use buildings foundation piles as vertical heat exchanger; thus a heat exchanger pile is a pile foundation equipped with a channel system, so that a heat carrier fluid can be circulated in order to exchange heat with the surrounding ground. A set of heat exchanger piles, usually coupled with a heat pump, can be then used for heating and/or cooling purposes. The advantage of such a system is its ability to use energy of the environment without too high costs.

This technology is relatively new and some problems remain to be solved such as the long term thermal behaviour of the underground; indeed if some precautions are not taken, the piles could freeze, which could lead to severe building's damages.

The main goal of this study is to establish a list of simple rules and recommendations useful to the realisation of such systems. For that, a numerical simulation model has been developed and validated with measurements on existing buildings.

Heat exchanger piles system description

Figure 1 shows the basic idea of such systems.

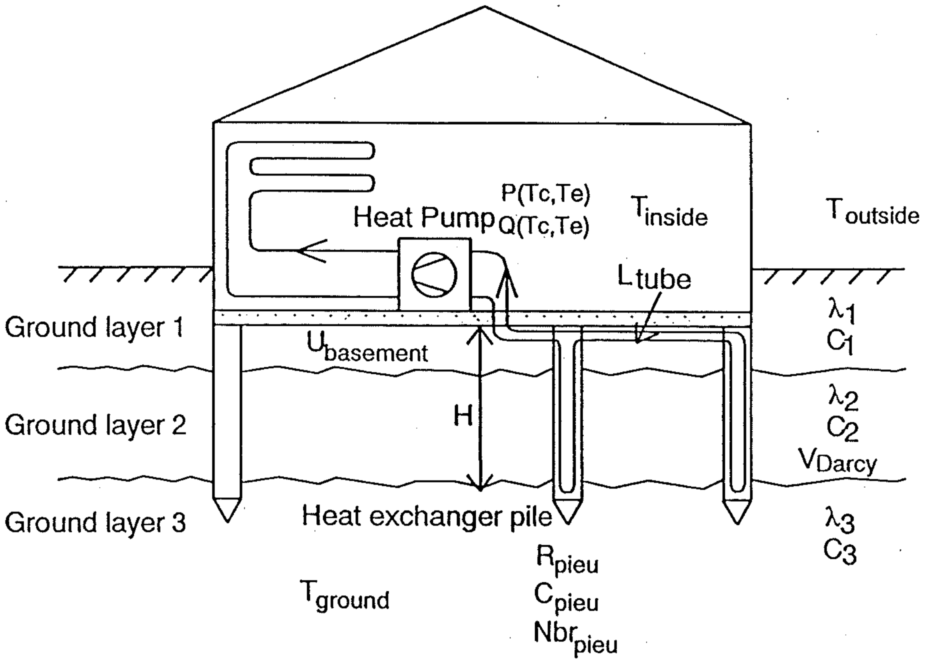

Figure 1 : Heat exchanger piles system; the main parameters which affect the thermal behaviour of such concept are also shown

The piles diameter can range from 30 cm up to 150 cm, and their length from 10 m up to 30 m (or even more). They can be equipped with single, double, triple or even quadruple U shape fluid carrier pipes.

Depending on the geological conditions and on the exploitation constraints, the thermal power which could be sucked per pile's length is around 25 to 100 W/m, which correspond to an annual energy taken from the ground in order of 60 to 150 [kWh/m·an]. Thus depending of the number of piles, rather large buildings (up to a few MW heating power) could be equipped with such system.

The piles can also be used to « extract » cold during the summer for cooling purposes, either directly or by using the HP in a reverse mode. This procedure has the advantage to balance the heat extracted during the winter, thus to avoid the long term decrease of the underground temperature. In some case, it could even be worth to reinject heat during the summer, for example with solar collectors; the ground under the building is then used as a low temperature heat storage.

Mathematical simulation model

As transient phenomena play an important role in such systems, it is a must to use a dynamic simulation model in order to be able to simulate the instantaneous as well as the long term processes. The dynamic simulation programme TRNSYS [1] is chosen to develop the simulation tools. Its modular and flexible structure allows the simulation of the whole system, including the short transient behaviour of the heat pump as well as the long term changes of the underground temperature. Some modules like the TRNSYS version of the Duct Storage Model DST [2] devised for the simulation of a ground duct heat storage, is adapted for the simulation of heat exchanger piles. For example, the influence of a regional ground water flow, the heat capacity of the piles, as well as the heat transfer of the horizontal connections between the piles and the heat pump can be estimated. Another model, the Superposition Borehole Model [3], devised to simulate multiple heat extraction boreholes, is integrated into TRNSYS, so that the influence of an irregular arrangement of heat exchanger piles can be assessed.

And finally, the heat pump model YUM (Yearly Utilisation Model for Calculating the seasonal Performance Factor of Electric Driven Heat Pump Heating System], also integrated into TRNSYS [4], enable the simulation of the heat exchanger piles as part of a complete heating and/or cooling systems.

Main results

Our mathematical simulation model is compared with experimental data from 4 different existing installations, ranging from 80 up to 570 piles. As it can be seen on figure 2, if we introduce the correct parameters (like ground thermal conductivity and water flow, utilisation sequences, building characteristics, ...) the model is perfectly able to reproduce the thermal, and thus the energetic behaviour of such a system.

In this case (Finkernweg, Switzerland), it is obvious that the heat exchanger piles are undersized (70 [W/m], no ground water flow, no summer recharge); the main ground temperature tends to decrease as a function of time, which could lead in a few years to severe piles damages (freezing). This case shows the need to carefully design such systems, for example by a simulation tool like that one presented in the above chapter.

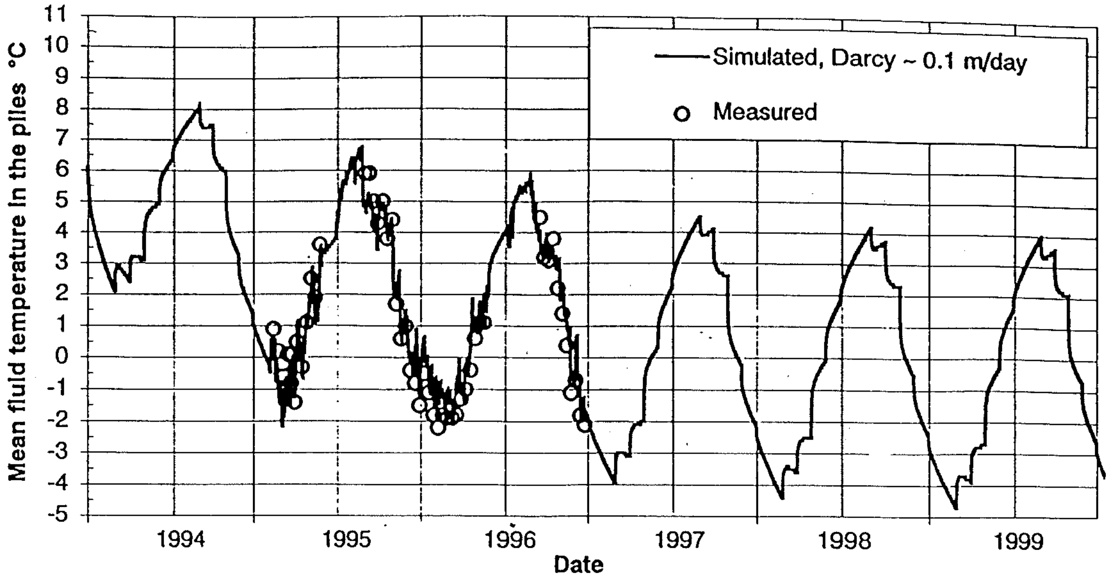

Figure 2 : Evolution of the temperature as a function of time of the carrier fluid circulating in the heat exchanger piles (Finkernweg, CH); results of the simulation are compared with measured data.

It is difficult to pull general rules for this kind of system, since it depends on a lot of parameters. However, a sensitivity analysis with our simulation model is conducted on a reference case (λ ground = 2 [W/m·K], Darcy's velocity = 1.10^{-5} [m^3water/m^2·s]). This shows the major influence of the ground characteristic parameters; in the figure 3, the influences on the energy extracted by the heat exchanger piles of the ground thermal conductivity (a) and of the underground water flow (b) are shown.

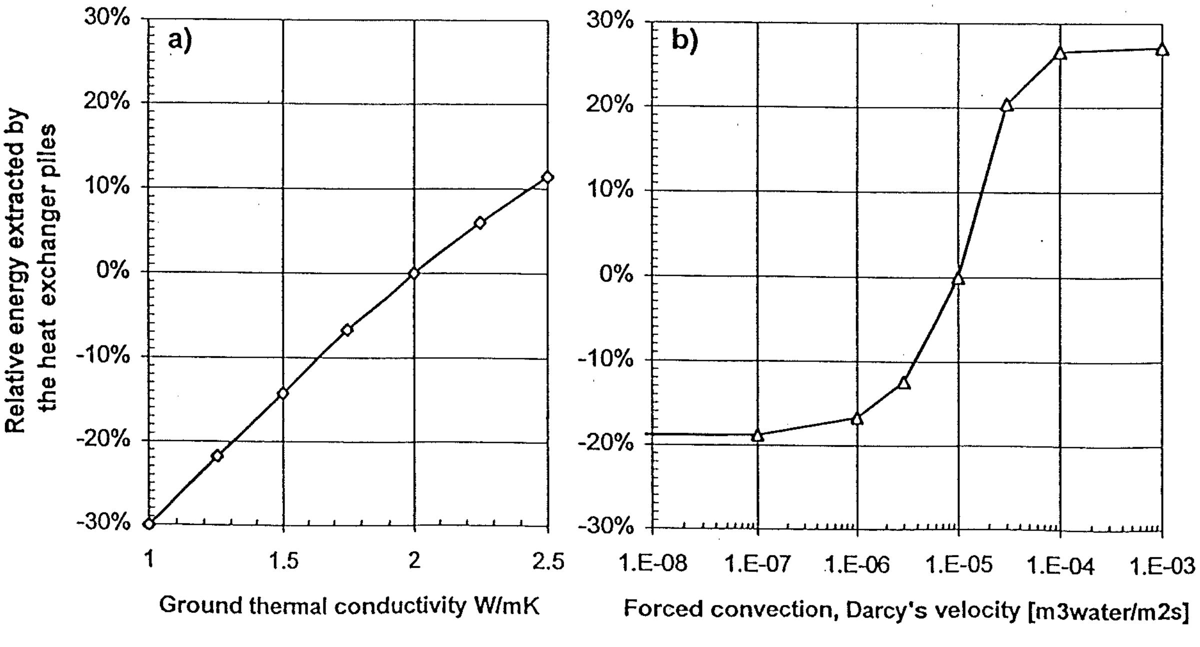

Figure 3 : Influences on the energy extracted by the heat exchanger piles of the ground thermal conductivity (a) and of the underground water flow (b)

It is clear that these parameters above can have an important effect on the overall efficiency of such a system. However, it is to note that the heat pump tends to flatten these effects; the energy delivered by the heat pump will not be too much affected by these parameters, but on the other hand, the temperature of the ground will change faster.

Recommendations and conclusions

Technically, this concept is relatively simple; some buildings, mainly in Switzerland and in Austria, already use this technology without major problems.

However, it is important to correctly design such systems. It has been shown that the undersizing of the energy piles leads to a progressive cooling of the ground, which could possibly freeze in the immediate vicinity of the piles. This could lead to the loss of the piles, with all the consequences for the static of the building. On the other hand, an oversizing of the system, which increases the investment cost, does not improve its overall efficiency. Such a design needs thus a precise modelisation, like for example with the tools developed in our institute.

For a rough pre-design, some simple rules can be pulled out :

- The forced convection (regional ground water flow) is a dominant parameter concerning the design of an energy piles system.
- As a first approximation, 1 meter of energy pile is enough to heat 2 m^2 of inner space.
- Depending on the geometry and on the underground characteristics the specific power per energy piles' length is between 25 and 100 [W/m], which corresponds to an annual energy between 60 and 150 (kWh/year·m].
- The energy piles can also be used for cooling purpose during the summer, even in a free cooling mode; in this case, the specific power is lower than in the heating mode.
- The control strategy of the heat pump is important; if its on-off frequency is too high, an overall efficiency decrease of more than 10% can be observed. This shows the importance to consider such concept from a systemic point of view rather than as the juxtaposition of single elements.

Once again, these above mentioned rules have to be utilised with caution and can not be applied in a general manner; each project has its own specific characteristics. However, actually, the experience and the modelisation tools exist to correctly design such a system.

References

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