PILESIM: a TRANSED Programme for the Simulation of Pile and Borehole Heat Exchanger Systems

Dr. D. Pahud, Dr. A. Fromentin
Laboratory of Energy Systems (LASEN)
Swiss Federal Institute of Technology in Lausanne (EPFL)
CH - 1015 Lausanne, Switzerland
E-mail: Daniel.Pahud@epfl.ch

Summary

PILESIM is a TRANSED programme devised for the simulation of heat exchanger pile systems. A heat exchanger pile system is a system which uses foundation piles for heating and cooling purposes. Borehole heat exchangers may also be simulated with PILESIM. PILESIM is based on the development of simulation tools with the TRNSYS programme, in which the non-standard TRNVDST component was adapted for the simulation of heat exchanger piles.

1. Introduction

A pile foundation is used when the upper layers of soil are too soft and compressible to support the loads of a superstructure, normally a building. A heat exchanger pile is a pile foundation equipped with a channel system, in which a heat carrier fluid can be circulated so as to exchange heat with the surrounding ground. The two main functions of a heat exchanger pile are thus to support the loads of a superstructure and to serve as a heat exchanger with the ground. A heat exchanger pile system comprises of a set of heat exchanger piles which are connected together hydraulically, and normally are coupled to a heat pump. Such a system is usually used for heating and/or cooling purposes.

Simulation tools of heat exchanger pile systems have been developed in the Laboratory of Energy Systems (LASEN), at the Swiss Federal Institute of Technology in Lausanne (EPFL) (Fromentin et al., 1997). Their development has been carried out with the help of measurements from existing systems for comparison and validation purposes. The well-known transient system simulation programme TRNSYS was used. A non-standard simulation model, devised for heat storage in the ground with borehole heat exchangers (Pahud et. al, 1996a), has been adapted for heat exchanger piles (Pahud et. al, 1996b).

In the framework of a research project relative to the simulation of a heat exchanger pile system at Zürich airport (Dock Midfield), the experience gained in the simulation of such systems was used to create PILESIM (Pahud, 1998). The development of the simulation tools that were validated with measurements from existing systems (Fromentin et al., 1997) forms the basis of PILESIM. The system's thermal performances, the utilisation potential of heat exchanger piles and a variety of system designs can be assessed with PILESIM. PILESIM offers easy use and relatively fast calculations. This programme may also be used for the simulation of ground coupled systems with a relatively large number of borehole heat exchangers.

2. The PILESIM Simulation Tool

PILESIM is a TRANSED programme of the TRNSYS environment (Klein et al., 1998). In other terms, PILESIM has been developed with TRNSYS and then adapted to the TRANSED format. The TRNSYS simulation tool is embedded in a user-friendly interface which provides online help and allows a non-specialist TRNSYS user to use the programme.

2.1 What does PILESIM simulate ?

In Fig. 1, a schematic view of the type of systems simulated by PILESIM is shown. A great flexibility has been given to PILESIM in order to provide a large variety of systems that can be simulated.

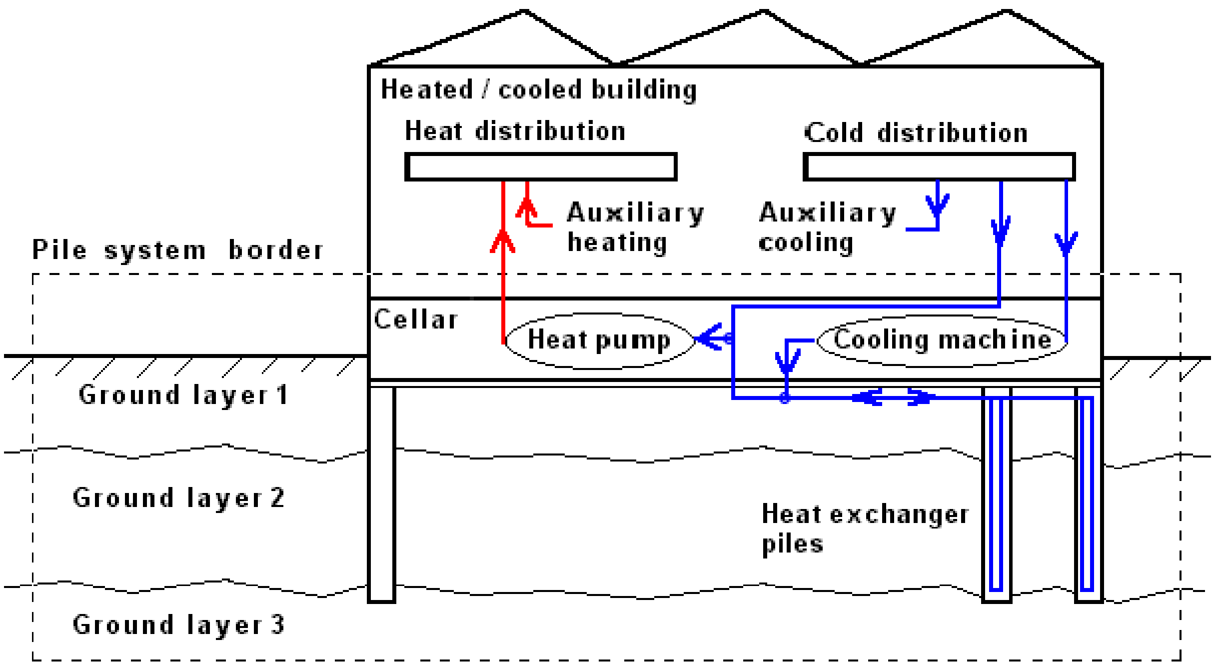

Fig. 1 System types and parts of the system simulated with PILESIM

The pile system border in Fig. 1 indicates the limits of the thermal simulations. The heat transfers are calculated from the ground to the thermal energy distributed in the building (heating and cooling). In particular, the heat transferred by the piles, by the horizontal connecting pipes under the concrete plate of the cellar, through the floor and ceiling of the cellar are assessed. The cellar, supposed to be unheated, has a temperature which depends on the indoor building temperature, the outside air temperature and the ground temperature below the building. The cellar may have the temperature of the outside air by an appropriate setting of heat transfer coefficients.

Four different types of systems can be simulated:

1. **heating only**
   a fraction or the totality of the heat demand is covered by a heat pump coupled to the piles. A thermal recharge of the ground can be realised during the summer.

2. **heating and direct cooling**[1]
   a fraction or the totality of the heat demand is covered by a heat pump coupled to the piles. A cooling requirement can be partly or totally covered by direct cooling with the piles. No cooling machine connected to the piles is used.

3. **heating and cooling with direct cooling or a cooling machine**
   a fraction or the totality of the heat demand is covered by a heat pump coupled to the piles. The cooling requirement is satisfied in priority by direct cooling with the piles. If a greater part of the cooling demand can be realised with the cooling machine[2], the cooling machine is used and takes over direct cooling. The thermal loads of the cooling machine are injected in the ground through the piles.

4. **heating and cooling with a cooling machine**
   a fraction or the totality of the heat demand is covered by a heat pump coupled to the piles. A fraction or the totality of the cooling requirement is also realised by a cooling machine connected to the piles. Direct cooling on the piles is not performed.

2.2 Which Types of Parameters Does PILESIM Require ?

A heat exchanger pile system is defined by 5 main categories of parameters:

1. **the ground characteristics**
   they define the thermal properties of the ground layer (up to 3), a possible regional ground water flow in each layer and the initial undisturbed ground temperature;

2. **the heat exchanger piles**
   up to 6 different types of heat exchanger pile can be defined;

3. **the ground-building interface**
   these parameters are related to the cellar and the horizontal connecting pipes;

4. **the heat pump and cooling machine**
   these parameters define the thermal performances of the heat pump and the cooling machine;

5. **the loading conditions for heating and cooling**
   the loading conditions are read from a file. However, these parameters allow the user to quickly change the annual energy requirements and the temperature levels of the distributed thermal energy.

---

[1] Direct cooling is realised by connecting the pile flow circuit directly to the cold distribution (without a cooling machine in between).

[2] The design power of the cooling machine is fixed before simulation by the user.

The loading conditions are given in hourly values. They are determined by the heat and cold demands and their corresponding temperature level. The hourly values are read from a text file. Predefined values are stored in files for several locations and can readily be used for a simulation. These predefined loading conditions are established on the basis of simple models which determine the space heating and space cooling requirements. The user also has the possibility to use his own loading conditions with PILESIM, in order to make them correspond to his particular problem. An temporal evolution of the hourly loading conditions is required for a whole year.

2.3 How May PILESIM Be Used ?

PILESIM can be used in different ways, depending on the degree of knowledge of a project. At an early stage, a pre-simulation can be performed by using a predefined file for the loading conditions, a constant performance coefficient for the heat pump and a constant efficiency for the cooling machine. Later in the project, more will obviously be known about the building. The pile system parameters will also be known better and more accurate loading conditions can be established with the help of another programme. They can be used to create an input data file for PILESIM, and a more precise simulation of the pile system can be performed, which may include the temperature-dependent heat pump performance coefficient and cooling machine efficiency.

2.4 What Does PILESIM Calculate ?

The energies transferred between the different components of the systems are calculated on a monthly or a yearly basis. A global heat balance of the system can be made month by month or year by year. The Sankey diagram shown in Fig. 2 can be established with PILESIM.

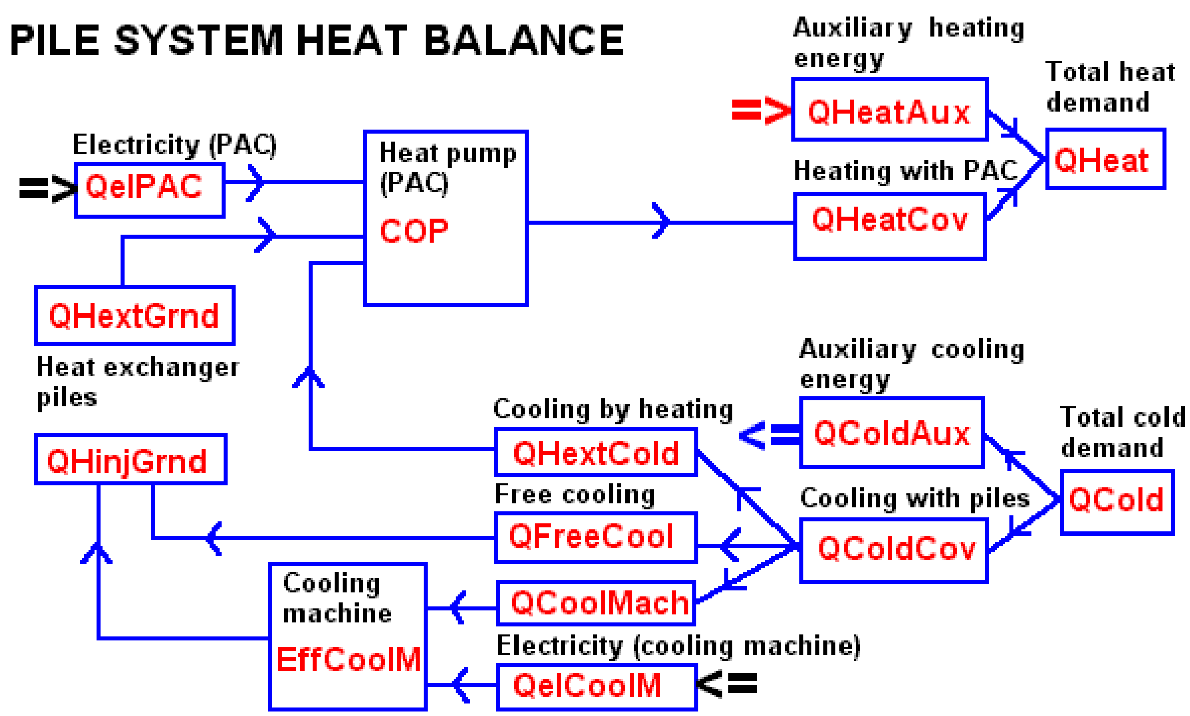

Fig. 2 Sankey diagram which can be established with the quantities calculated with PILESIM.

Temperature levels, the heat pump performance coefficient and cooling machine efficiency, etc. are also calculated. The influence of long terms effects on the results can be assessed for up to 25 years. The temporal evolution of some energy rates and temperatures are printed in a file for the last simulated year. They can be then plotted thanks to a functionality of TRANSED.

2.5 How Does PILESIM Calculate ?

Once the loading conditions are chosen and all the system parameters fixed, a simulation can be started. The undisturbed ground temperature is chosen for the initial conditions of the ground. The thermal simulation is performed with a time-step set to one hour. At each time-step, the operational mode of the system is determined, depending on the system type chosen, the current loading conditions and the system component's thermal performances (heat pump, cooling machine, heat exchanger piles, etc.). Three basic operational modes are possible (cf. Fig. 3).

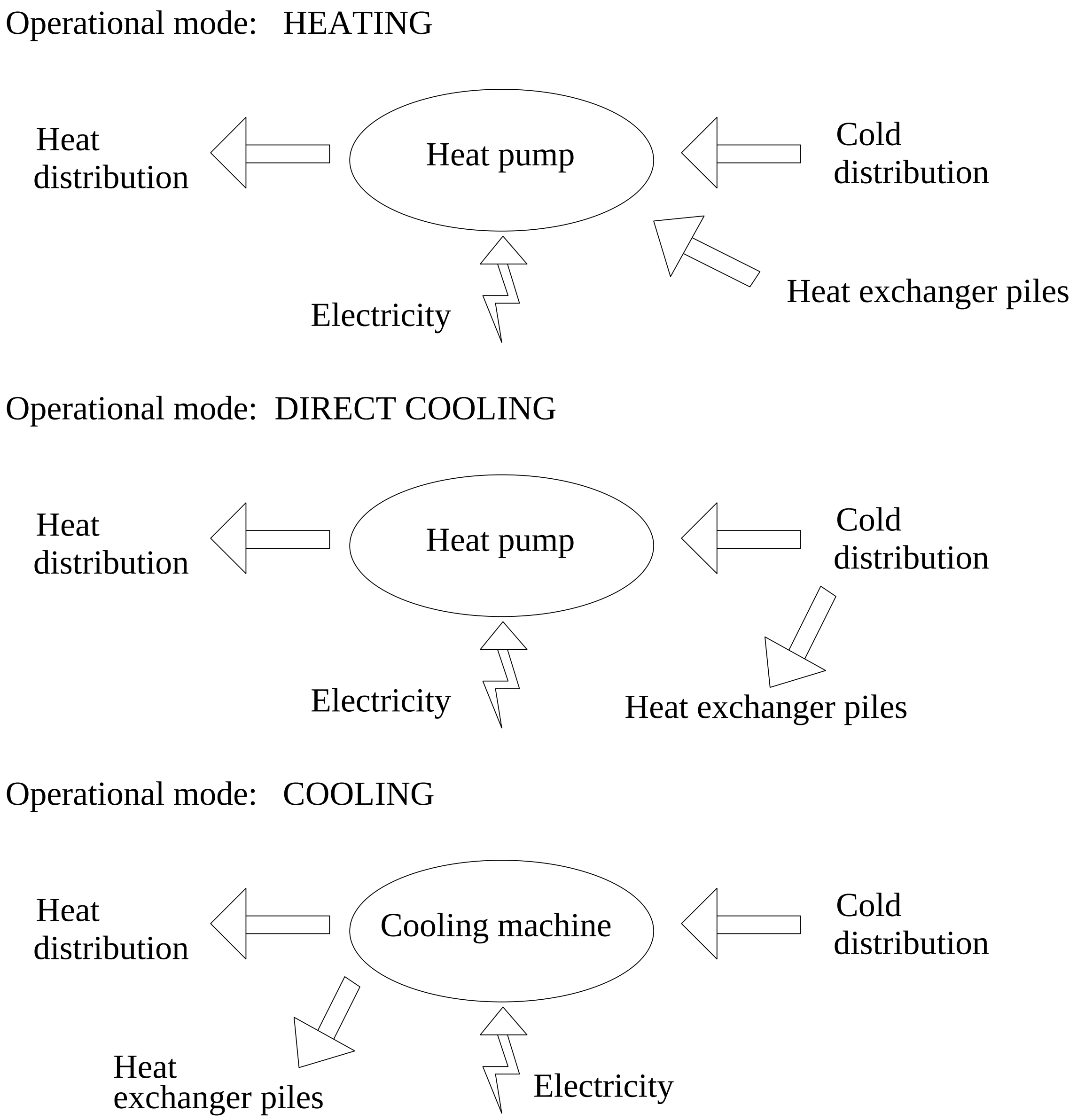

Fig. 3 The three drawings illustrate the three basic operational modes of the heat exchanger pile system. The arrows indicate the direction of the heat transfers.

Heating and cooling can be simultaneously satisfied with each of these three operational modes. The mode that satisfies the greatest part of the heating and cooling demands is chosen. If there is no cooling requirement when heating is needed or vice versa, the three basic operational modes are reduced to three simple situations:

- heating with the heat pump connected to the piles;
- direct cooling with the piles connected to the cold distribution;
- cooling with the cooling machine connected to the piles.

The heat pump performance coefficient and the cooling machine efficiency may depend on the temperature levels of the heat carrier fluid in the condenser and evaporator. The performance coefficient determines the heating power, with the help of the design electric power of the heat pump, set to a constant value. If the heating requirement is smaller, the heating power is decreased to match the heating requirement. As a result, the electric power consumed by the heat pump and the heat rate extracted at the evaporator are recalculated with the help of the performance coefficient. The heating power of the heat pump may also be reduced by the temperature constraint associated with the heat carrier fluid which circulates in the piles. This constraint requires that the fluid temperature in the piles never drops below a user given value, normally fixed at 0 °C. If this is not the case, the heat rate extracted by the heat pump is decreased until the fluid temperature satisfies the criterion. As a result, the heating power delivered by the heat pump is reduced. In consequence, an oversized heat pump will not yield much more heating energy per year than a correctly sized one. A temperature constraint is also given for the highest allowed fluid temperature in the pile flow circuit. The same kind of considerations apply for the cooling machine.

PILESIM assumes an optimal system control: the best operational mode is selected; the heating and cooling powers are adjusted to the heating and cooling demands if necessary, while the temperature constraints on the heat carrier fluid in the piles are satisfied. The influence of frequent starts and stops of the heat pump and cooling machine is not taken into account, although a penalty value can be specified on the performance coefficient and efficiency.

2.6 Main Assumptions of the PILESIM Simulation Tool

As previously mentioned, the system control in PILESIM is optimal. Other assumptions are related to the specificity of the simulation model used. The heat pump model is based on the model used in the MINSUN programme (MINSUN, 1985). The heat exchanger piles are simulated with TRNVDSTP (Pahud et al., 1996b). The main assumptions are:

- the number of heat exchanger piles is relatively large;
- the spatial arrangement of the heat exchanger piles is more or less regular;
- the ground area occupied by the heat exchanger piles has a shape which is more or less the shape of a circle or a square.
- the heat exchanger piles have about the same active length. (The active length of a heat exchanger pile is the length along which radial heat transfer takes place.)

The first assumption is probably the most restrictive one. It implies that most of the heat exchanger piles are surrounded by other heat exchanger piles. In other terms, PILESIM is not suited for the simulation of a single heat exchanger pile or a several heat exchanger piles arranged in a line. When the ground area occupied by the heat exchanger piles is far from being a circle or a square, or the pile arrangement is highly irregular, the average pile spacing; which is a input parameter to PILESIM, can be calibrated with another programme. (For example, TRNSBM (Eskilson, 1986; Pahud et al., 1996c) can be used. TRNVDSTP has been preferred to TRNSBM, due to its greater flexibility, easier use and a much more faster execution time.)

Conclusion

PILESIM is a new simulation tool for heat exchanger pile systems developed with TRNSYS. People involved in the planning of a heat exchanger pile system should be able to use PILESIM, although they are not necessarily accustomed to TRNSYS. System thermal performances, utilisation potential of heat exchanger piles and a large variety of system designs can be assessed with PILESIM. PILESIM should be available for sale at the beginning of 1999.

Acknowledgements

The authors would like to acknowledge the Swiss Federal Office of Energy for its financial support.

References

Fromentin A., Pahud D., Jaquier C. et Morath M. (1997), Recommandation pour la réalisation d'installations avec pieux échangeurs. Empfehlungen für Energiepfahlsysteme, Rapport final, décembre 1997, Office fédéral de l'énergie, Bern, Switzerland.

Klein S. A. et al. (1998) TRNSYS. A Transient System Simulation Program. Version 14.2. Solar Energy Laboratory, University of Wisconsin, Madison, USA.

MINSUN (1985) Central Solar Heating Plants with Seasonal Storage. The MINSUN Simulation and Optimization Program. Application and User's Guide. International Energy Agency, Solar Heating and Cooling Programme, Task VII.

Pahud D., Hellström G. and Mazzarella L. (1996a) Heat Storage in the Ground. Duct Ground Heat Storage Modelfor TRNSYS (TRNVDST). User Manual for the October 1996 Version. LASEN - DGC- EPFL, Switzerland.

Pahud D., Fromentin A. and Hadorn J.-C. (1996b) The Duct Ground Heat Storage Model (DST) for TRNSYS Used for the Simulation of Heat Exchanger Piles. User Manual, December 1996 Version. Internal Report. LASEN - DGC- EPFL, Switzerland.

Pahud D., Fromentin A. and Hadorn J.-C. (1996c) The Superposition Borehole Model for TRNSYS (TRNSBM). User Manual for the November 1996 Version. Internal Report. LASEN - DGC- EPFL, Switzerland.

Pahud D. (1998) PILESIM: Simulation Tool of Heat Exchanger Pile Systems. User Manual. Laboratory of Energy Systems, Swiss Federal Institute of Technology in Lausanne, Switzerland.