Energy Saving Calculations and Monitoring of Ground Source Heat Pump Systems

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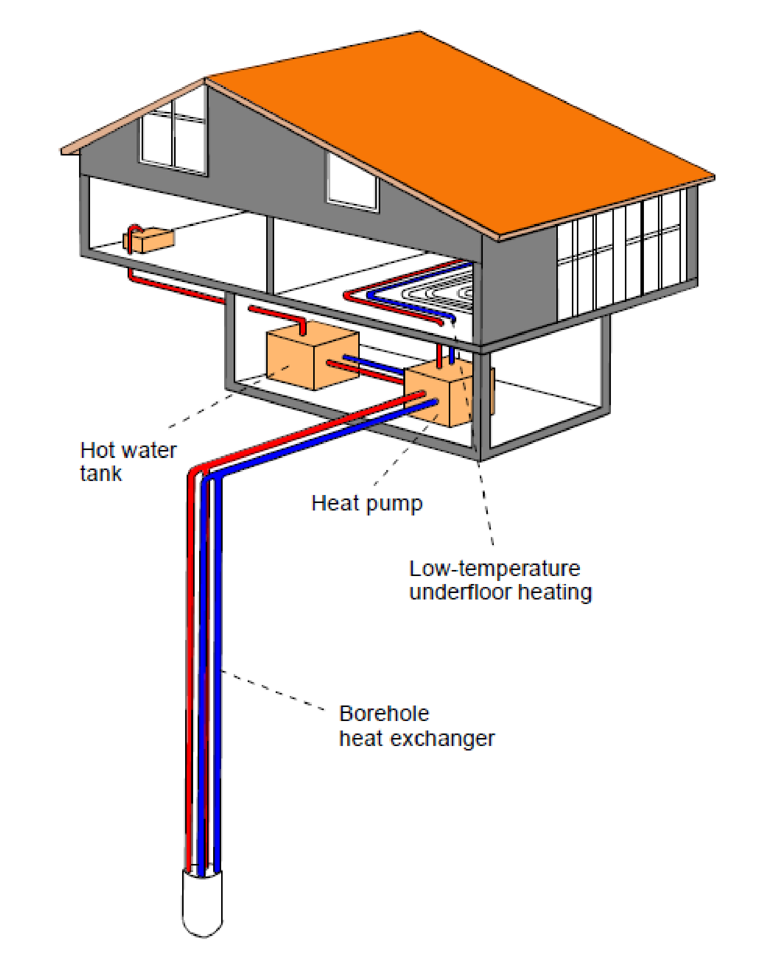
Basics of Ground source heat pump (GSHP) systems

- GSHP systems are promising alternatives of traditional fossil fuel and electric power driven heating and cooling systems for **buildings with good thermal insulation**.
- Ground is used as a heat source for heating (winter-time heating or DHW production) and as a heat sink for cooling (in summer).
- Closed systems: vertical or horizontal ground heat exchangers with heat transfer fluid circulating in a closed loop.
- Open system: ground water, surface water, standing column well systems.
- Heating: low level heat **stored** in the soil is exploited, temperature is increased by heat pump. The heat removed from the soil is **slowly recovered** from the surface (solar energy), from deeper layers (geothermal energy) and through the movement of underground water (solar+geothermal energy).
- Cooling: GSHP performs better than the conventional air source split conditioner units. Direct cooling is possible.
- Mixed mode: the same ground heat exchangers and heat pump can be used for both heating and cooling.



Basics of Ground source heat pump (GSHP) systems

Long term behaviour

- Heating (or cooling) dominated systems: problem of temperature depletion, system performance decrease over the years.
- When the same ground block is used for heating and cooling, then a part of the removed and added heat is buffered in the ground between the seasons, decreasing the long term depletion and increasing the total system performance.

Special systems

- Solar-geothermal combined systems: the surplus energy from the solar collectors in summer is put into soil. A type of seasonal heat storage. Underground heat insulation is not possible, high level of heat loss. Problem of sizing of solar collectors for borehole's capacity.
- Deep borehole heat exchangers: re-use of abandoned wells, up to 2 000 -3 000 m! Only for heating. Can be used without heat pump (heat loss until ~500 meters instead of gain). Building should be located close to the well. Low heat loss (or even heat gain!) in underground fluid distribution pipes.

Heat pumps

- Electric compression heat pumps, COP = 3.5-5.0 (depends on temperature leves).
- Gas absorption heat pumps: less efficient, more expensive, new in the market. Viable in countries where electricity is relatively expensive and natural gas is relatively inexpensive.
- Gas engine driven compression heap pumps: very high cost.

Economics of GSHP systems

Prerequisite: suitable ground area must be available below or near (or close to) the building

The economic viability of GSHP system depends on the following factors:

- Heating (and cooling) load of the building;
- Required inlet fluid temperature for the heating (and cooling) system;
- Ground layers and ground thermal parameters (initial temperature distribution, thermal conductivity and heat capacity), presence and flow of groundwater (permeability, hydraulic gradient);
- Parameters of the selected system parts (ground heat exchanger parameters, performance of the heat pump at different temperatures, etc.);
- Initial costs (costs for drilling permissions, drilling, ground heat exchangers, heat pump, piping, etc.);
- Availability or lack of natural gas supply on the site;
- Actual and future fees for electrical energy and natural gas, including special fees for alternative energy systems;
- Availability or lack of external financial support for alternative energies (governmental support).

Economics of GSHP systems

- Many factors, and some of them can have some uncertainties → the system design and economic calculations can become uncertain.
- Rule of thumb: GSHP system can only be economical in case of well isolated buildings having low-temperature heating system (floor or wall heating).
- Typical factors that increase the viability of GSHP systems: new building, lack of local natural gas supply, additional governmental supports, well balanced energy load requirements for winter heating and summer cooling.
- Typical factors that discourage the investors: high investment costs, long and expensive legislative procedures required sometimes for drilling permission, uncertainties regarding the long term operation of the system.

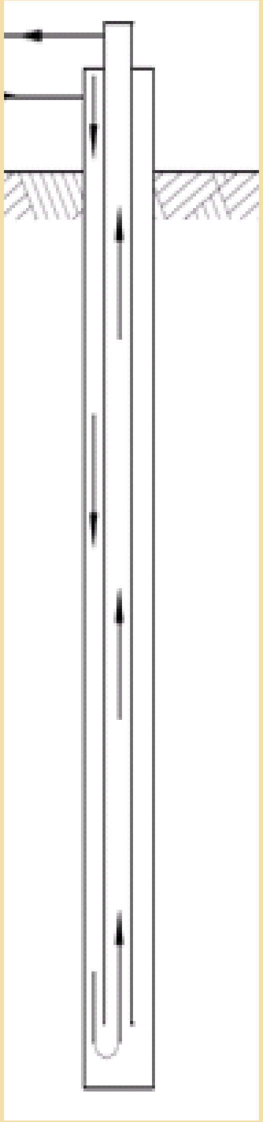
Modeling of GSHP systems

- Computer simulation is an effective tool to design GSHP systems and to supply parameters for economic calculations. Based on the simulation results the economic calculations can be made much more accurate.
- With the help of simulations, the over- and under-sizing of the ground heat exchangers can be avoided, so the initial costs can be reduced while the long term safe operation is still ensured.
- Analytical models, tabulated design data: mainly for standard systems, in case homogenous soil.
- Numerical models: mainly for special or experimental systems (passive houses, solar-geothermal combi-systems, transient loads), in case of different soil layers, underground water flow.
- The input parameters of the model must be carefully selected to get accurate simulation results.
- Probably the most difficult task is to prospect the structure of the underground layers, to determine soil parameters at different layers and to estimate the groundwater flow.

Integrated GSHP simulation system

With a cooperation between *Eötvös Loránd Geophysical Institute of Hungary* (ELGI) and the *University of Florence, Italy*, an integrated GSHP simulation system has been developed.

This system is a unique combination of three separate numerical models: an underground heat and fluid transport model (HST3D), a borehole heat exchanger model (BHE-SIM) and a transient energy system simulation tool (TRNSYS).



1. HST3D

The HST3D of UGSG simulates ground-water flow and associated heat and solute transport in two or three dimensions.

Public domain. It can simulate both heat conduction and heat convection through the movement of underground water, using finite-difference technique.

2. BHE-SIM

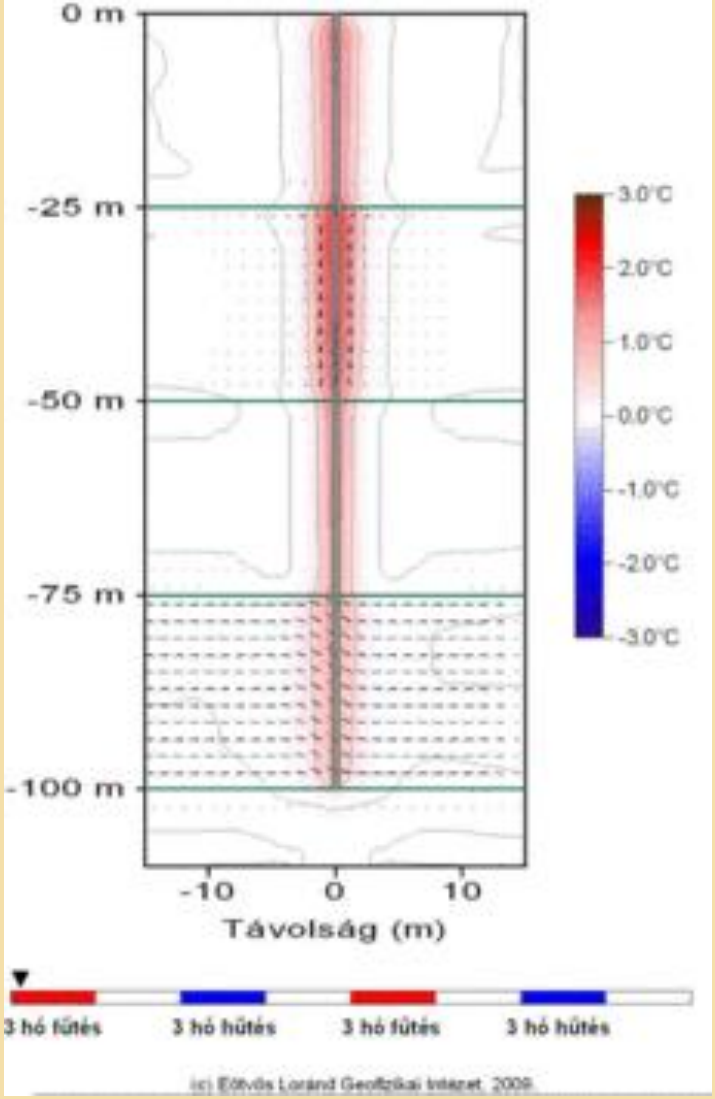
Developed in ELGI.

Simulates a coaxial-type heat exchanger (geothermal probe).

By the numerical combination of HST3D and one or more BHE-SIM heat exchanger models, simple and complex ground heat exchanger systems can be simulated.

According to the simulation results it can be assumed that after long-term operations the coaxial-type borehole heat exchanger models have very similar thermal behavior than the commonly used U-type borehole heat exchangers.

Example for a simulation result



Integrated GSHP simulation system

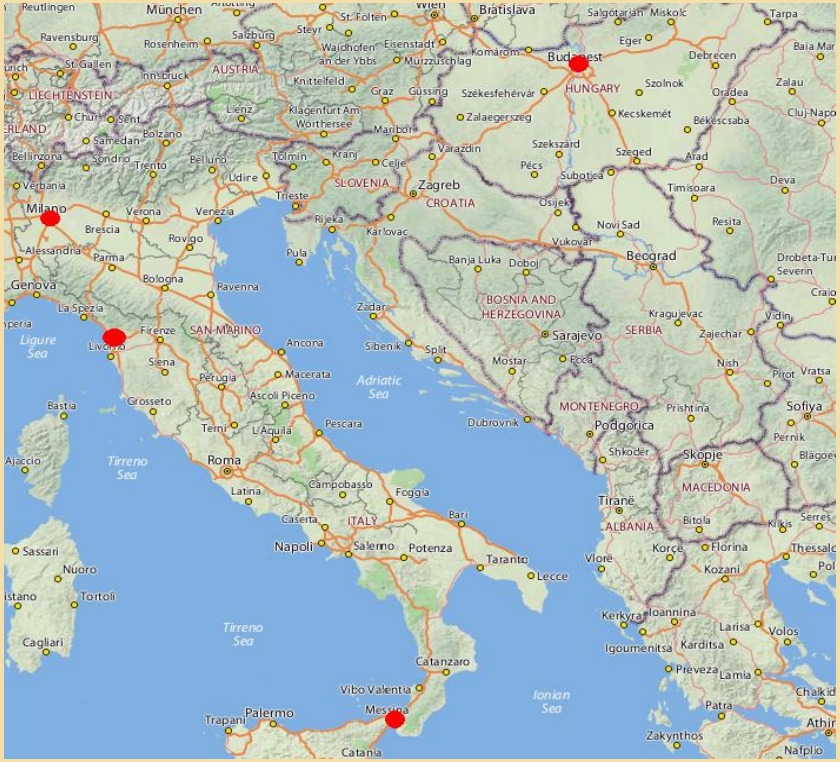
3. TRNSYS

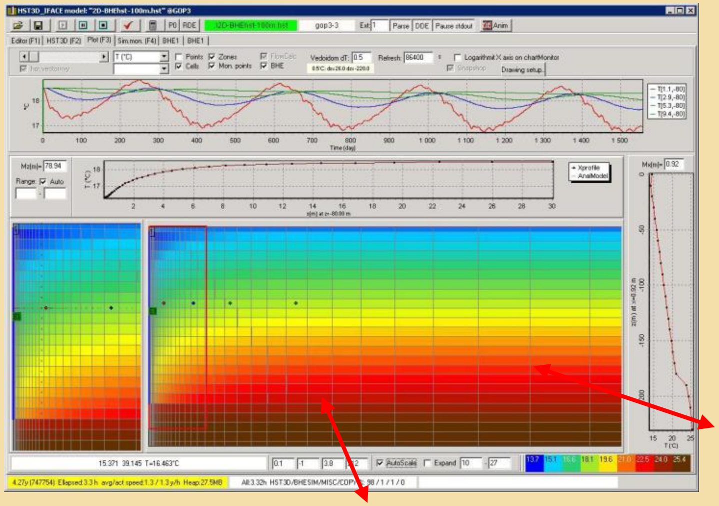
- Energetic simulation of buildings and heat pump system (including the calculation of transient heating and cooling loads based on meteorological files, the simulation of the heat pump operation and simulation of control elements)
- TRNSYS has some components to model borehole heat exchangers. These components use simple formula.
- For our studies, the BHE-SIM/HST3D underground model is coupled with this TRNSYS program.
- For the coupling a new TRNSYS component HST3D-BHE has been created. This component is an interface program that transfers input and output data in every time step between the TRNSYS model and BHE-SIM/HST3D model. These input and output values are the boreholes' inlet and outlet temperatures and flow rates.

GSHP model for a family house

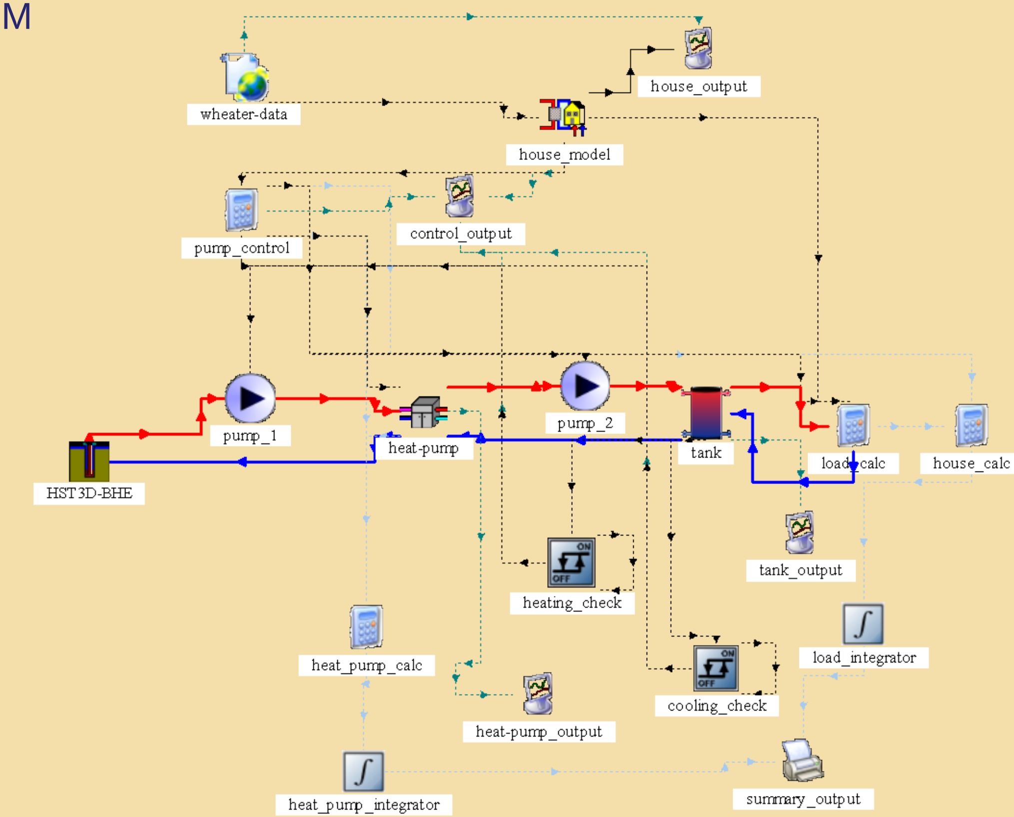
A model for a fictive family house has been created that is heated and cooled by a GSHP system. Four different climatic conditions: Budapest, Milan, Pisa and Messina.

- A single zone building model with energy/degree-hour concept
- Two outlet temperatures: 45˚C and 55˚C
- One single borehole: 180 m (2D model)
- Soil effective thermal conductivity: 2 W/m·K, soil effective volumetric heat capacity: 2000 kJ/m3·K
- Impermeable and homogeneous soil was assumed.
- Initial ground temperature distributions: top temperature representing the average surface temperature and a geothermal gradient.
- Budapest and Pisa: 5 ˚C/100 m
- Milan and Messina: 3 ˚C / 100 m
- Simulation period: 20 years

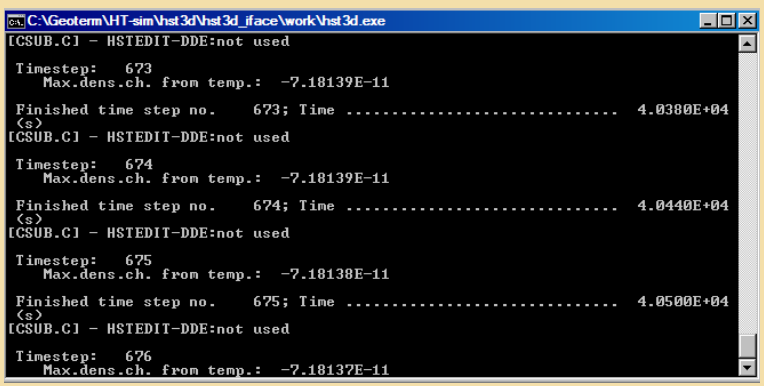




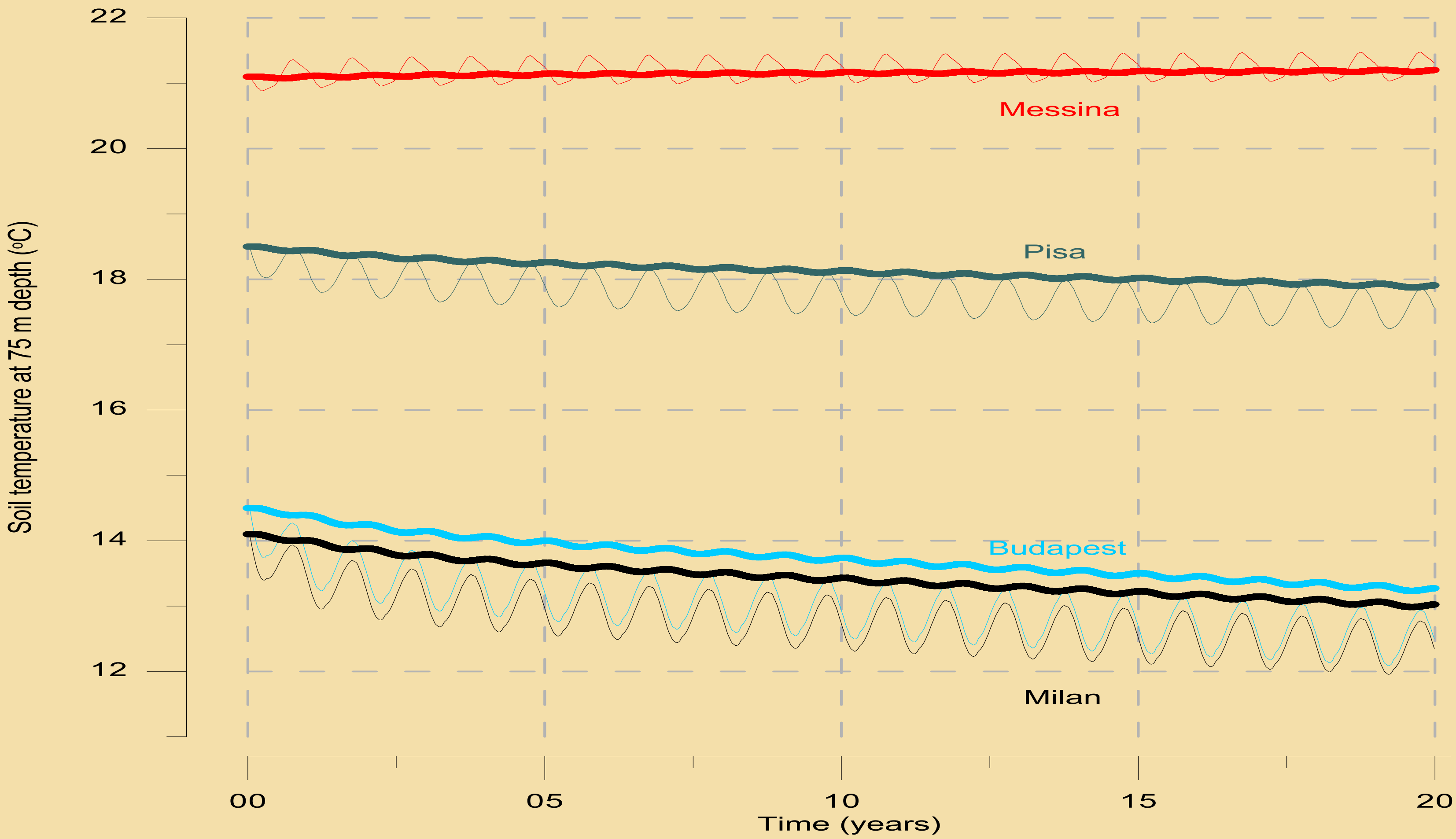
BHE-SIM



TRNSYS
modell



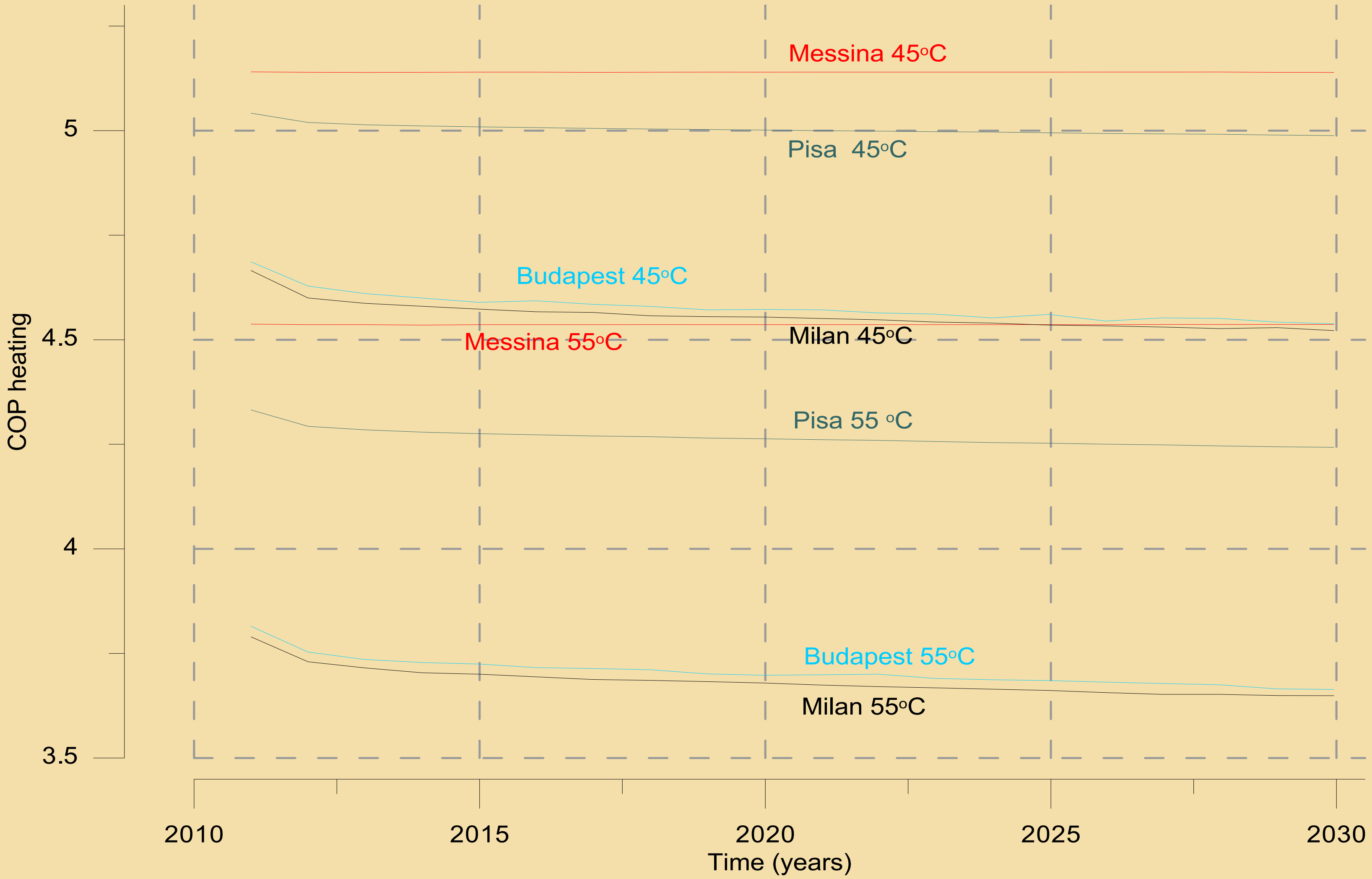
HST3D
code



A talajszonda melletti talajhőmérséklet változása 75 méter mélységben, egy szondához közelebbi és egy távolabbi pontban, 55 ˚C-os fűtési hőmérséklet mellett.

Calculated underground temperature changes at 75 meters; thick curves show the temperatures at 9 meter thin curves show the temperature at 3 meter distance from the borehole axis.

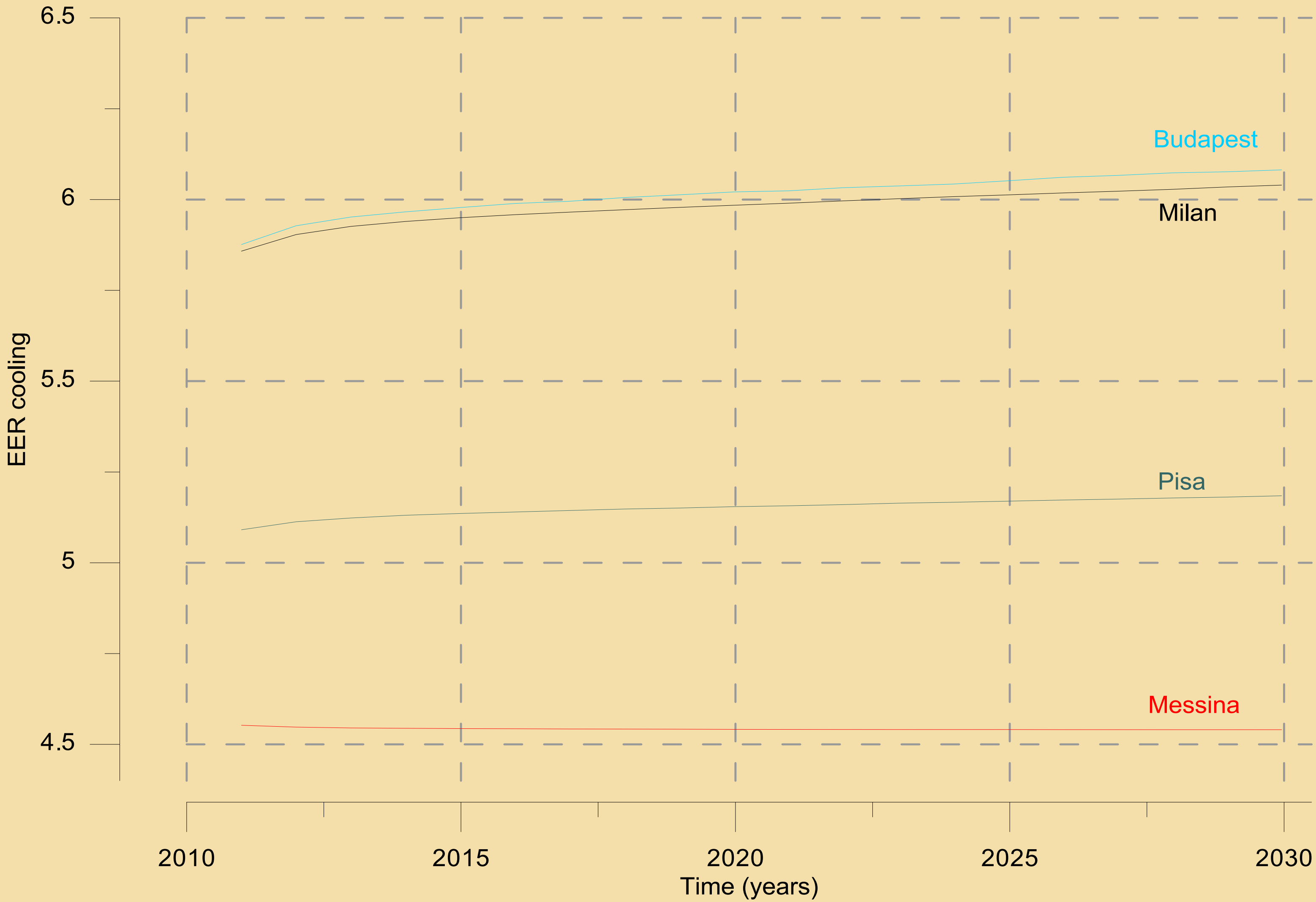
Fűtési COP érték változása
COP variations during the 20 years simulation period.



Average COP (coefficient of performance) values describe the yearly average heating efficiency of heating systems. They indicate the ratio of total yearly heating energy provided by the unit relative to the total yearly amount of electrical input energy required to drive the heat pump.

Hűtési EER érték változása

EER variations during the 20 years simulation period.



Average EER (energy efficiency ratio) values describe the yearly average cooling efficiency of air conditioning systems. They indicate the ratio of total yearly cooling energy provided by the unit relative to the total yearly amount of electrical input energy required to drive the heat pump.

Energy saving calculations

A basic cost saving calculation has been made based on simulation results.

The energy bills of the GSHP system are compared with energy bills of a reference traditional system having similar heating and cooling loads.

Initial costs and additional costs (bills for circulating pumps power consumption or system maintenance costs) are not considered. Goal: comparing the annual savings.

Reference system:

Air conditioning split for cooling with a constant EER value of 3.22 (commercial split unit of energy class "A")

Gas boiler with an average efficiency of 90%

For electricity and natural gas bills, the prices valid at the first semester of 2009 in Italy and Hungary were considered.

In Hungary it is possible to apply a special reduced electricity price "Geotarifa" for ground and air source heat pump systems.

For Italy a lower price for electricity has been considered using a "Tariffa BTA" from ENEL company.

	Electricity price €/100 kWh	Natural Gas prices €/GJ	Natural Gas prices €/100 kWh
Italy	20.93/12*	21.04	7.57
Hungary	14.83/9.65*	12.16	4.38

Location	Total annual saving (55°C) €	Total annual saving (45°C) €	Saving percentage increase [%]
Budapest	206/502*	378/614*	84/22*
Messina	200/247*	224/261*	12/6*
Milan	564/1016*	786/1143*	39/13*
Pisa	478/723*	578/780*	21/8*

Total annual savings (heating and cooling), and saving increase percentage due to lowering the heating temperature from 55℃ to 45℃.

**Special prices: Geotarifa and BTA*

The high saving rates in Milan and Pisa are due to the smaller difference between the price of the natural gas and electricity in Italy.

In Hungary the gas price is relatively cheap making the conventional gas boilers more attractive. However, the *Geoterifa* in Hungary considerably improves the profitability of the system.

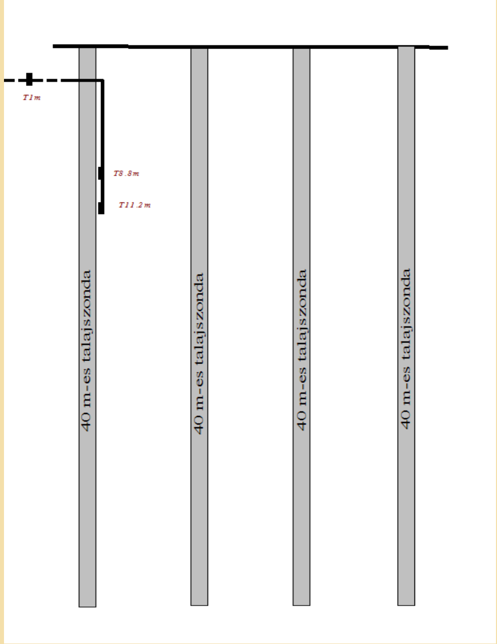
Lowering the heating temperature from 55˚C to 45˚C results in considerably larger savings, especially for the case of heating dominated sites (Budapest and Milan). This is due to the increased COP value of heating mode. However, realize special, low temperature heating in buildings (such as high area wall heating) requires higher investment costs.

Monitoring of GSHP systems

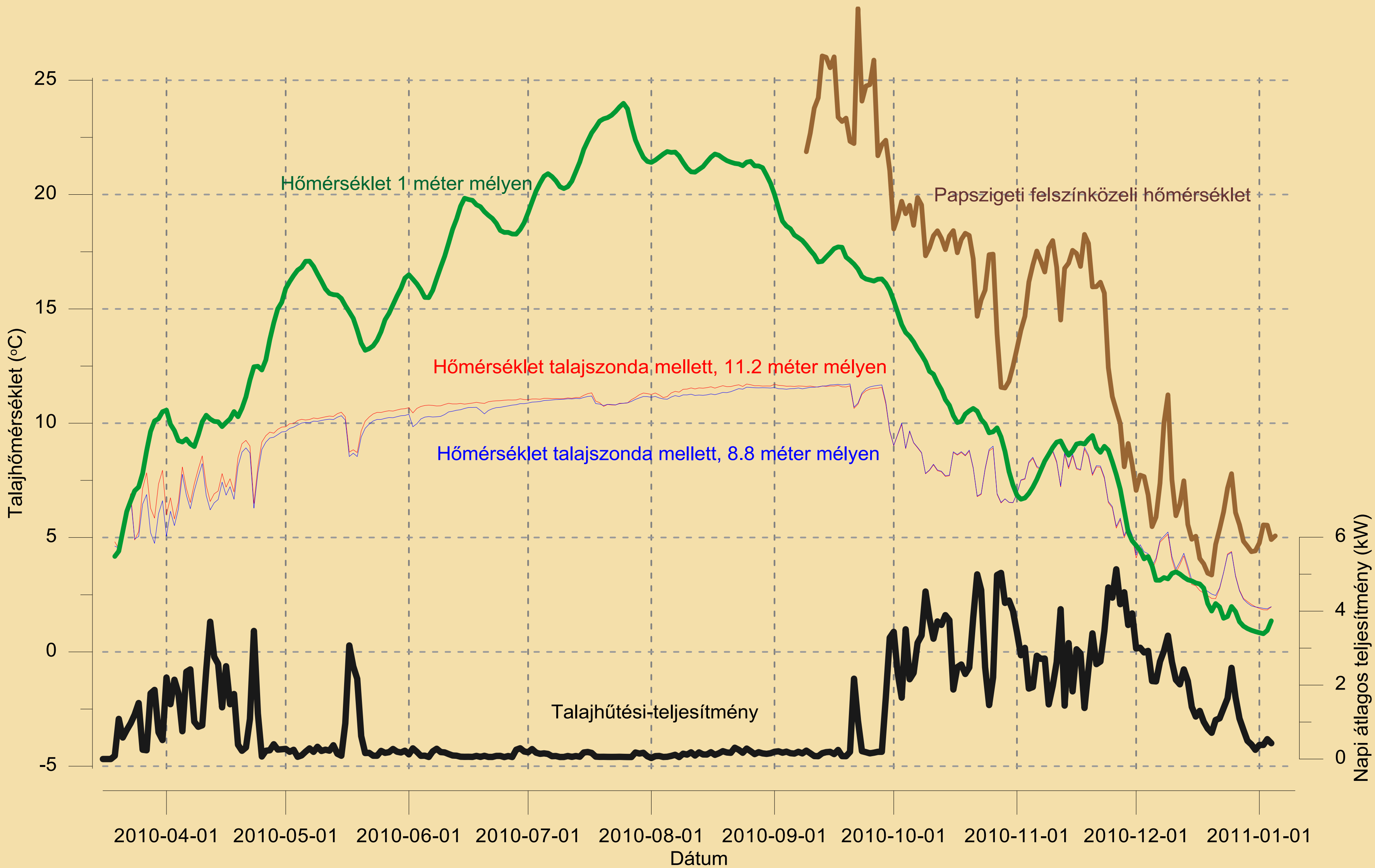
- When a GSHP system is already installed and in operation, the monitoring of underground temperature and heat flow and the monitoring of the equipments can be effectively used to check the system operation and to calibrate and validate the computer models.
- Soil effective thermal properties can be calculated.
- Conclusions for long term operation.
- ELGI has conducted tests for long term high precision underground temperature measurements for many years.
- Budapest University of Technology and Economics (BME) and ELGI have developed and tested a three axis heat flux sensor that is sensitive enough to measure the underground heat flux vector that can have very low values, especially in horizontal directions.
- These sensors can be used to monitor natural and induced temperature and heat flow changes until depths of several tens of meters.
- The data acquisition system developed for these sensors is easily expandable by other signal converters and sensors, such as different kind of temperature sensors, fluid flow meters or pyranometers.

Monitoring of a family house GSHP system

- From 2010 a small monitoring system has been installed at a GSHP system of a new family house in Gödöllő, Hungary.
- The heat pump is connected to four 40 meter long U-type vertical borehole heat exchangers.
- Heat pump supplies the energy for winter time heating, for summer-time cooling and for domestic hot water.
- The saturated soil has very good thermal properties for this application.
- The digital acquisition system continuously records: volumetric flow rate of the circulated fluid, the heat pump inlet and outlet temperatures, the far soil temperature at 1 meter depth and the soil temperatures at the perimeter of one borehole heat exchanger at depths of 8.8 and 11.2 meters.



Talajszonda-monitoring rendszer



Conclusions

- A complex numerical GSHP simulation system has been presented that has the strength of accommodating many different ground parameters, system configurations and load scenarios.
- A simple model is run for different climatic and operational conditions.
- The model can be easily modified to other ground, weather and design parameters.
- The cost analysis made from the results shows that relevant saving may be possible for an isolated family house whose heating and cooling are satisfied by GSHP. The rate of saving depends on local climate (so on the heating and cooling loads), on the required heating temperature and on the energy prices.
- We also presented a small monitoring system of a simple GSHP installation. As there are very few measured data sets on the operation of GSHP systems in Hungary, the results of the long term monitoring data of this station might become unique and of great importance.

Thank you for your attention