EasyPipes *Plus*

Detailed dimensioning tool for air-soil heat exchangers

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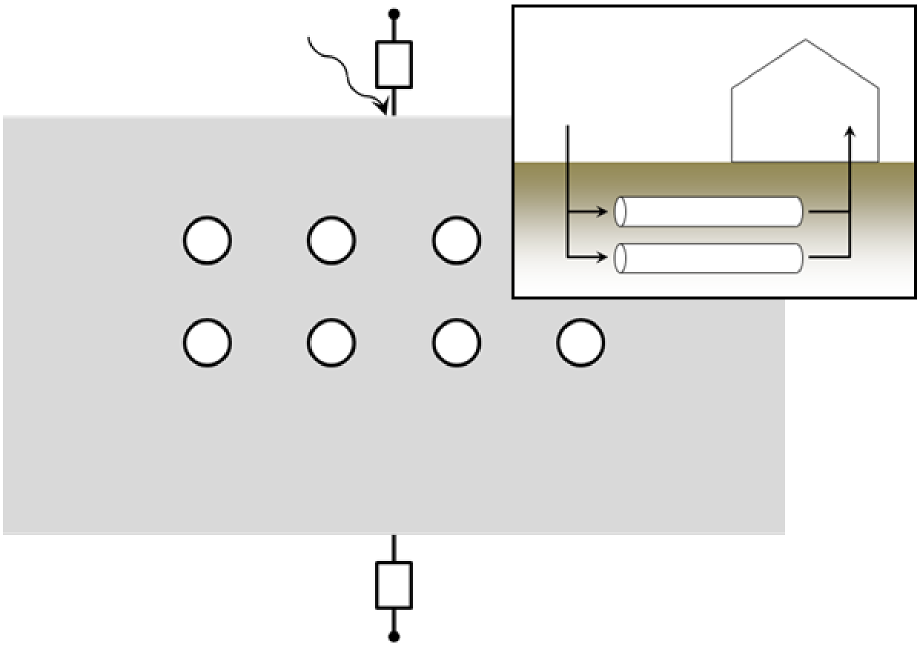

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General description

EasyPipes Plus is a front/end tool for dimensioning of air-soil heat exchangers. It is based on a numerical simulation algorithm, integrated into the Trnsys simulation environment, which takes into account transient flow patterns. It accounts for sensible as well as latent exchanges between airflow and pipes, diffusion into surrounding soil, as well as interaction with upper and lower border conditions.

The tools is driven by way of an Excel 2010 interface, and needs no other specific software.

Development of the tools originates from a PhD on air-soil heat exchangers elaborated by P. Hollmuller at University of Geneva. It further benefitted from following projects and funding:

- EasyPipes: Front/end numerical tool for simulation and dimensioning of air-soil heat exchangers, funded by the Swiss Federal Office of Energy.
- Stratégies alternatives à la climatisation (AlterClim), funded by Services Industriels de Genève (SIG).
- Building Energy Efficiency Project (BEEP), bilateral cooperation project between the Swiss Agency for Cooperation and Development of the Swiss Federal Department of Foreign Affairs and the Ministry of Power, Government of India.

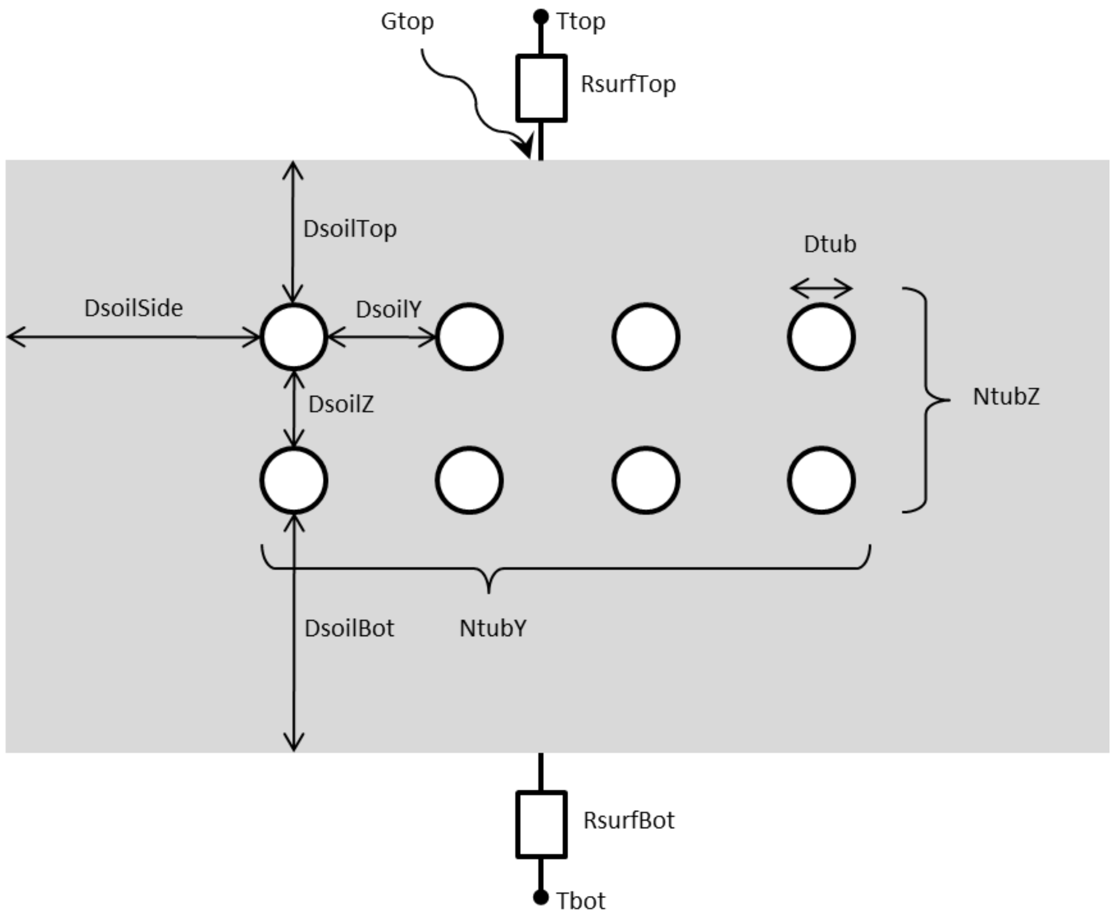
Disclaimer

The author, as well as the University of Geneva and the funding entities, deny any responsibility related to the use of this tool, in particular concerning the reliability of the results.

Geometry

The system is composed of an array of circular equidistant pipes (possibly in multi-layer) within a homogeneous soil:

- The geometry is defined by the pipe depth and inter-pipe distance, as well as by the available soil for heat diffusion below the pipes and next to them (typically 20 m, for complete absorption of yearly heat waves).
- Top and bottom border conditions can be either adiabatic or driven by temperature (and possibly solar absorption for the top surface), while lateral border conditions are adiabatic.
- Simulation can be performed on the entire pipe array (which can be very time consuming), or on a typical vertical section of the array, with adiabatic conditions at inter-axial pipe distance (disregarding lateral border effects).


Gtop
Ttop
RsurfTop
DsoilTop
Dtub
DsoilSide
DsoilY
NtubZ
DsoilZ
DsoilBot
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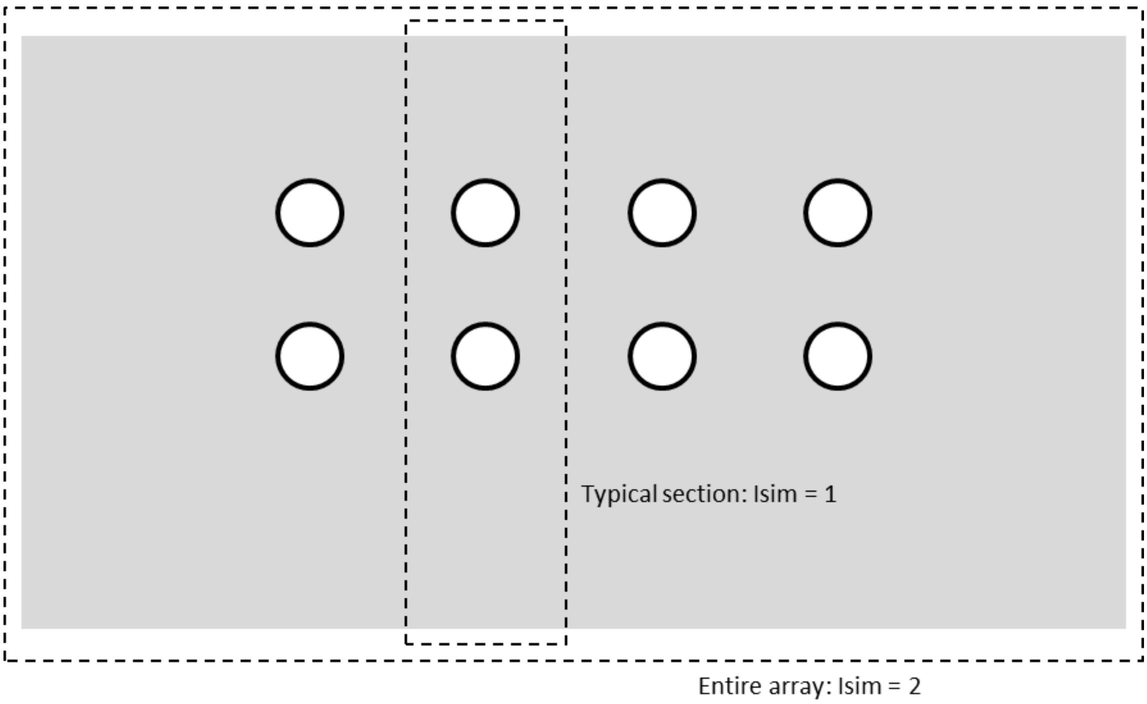
Typical section: Isim = 1
Entire array: Isim = 2

Parameters

The model is defined by following parameters.

Symbol	Unit	Description
Geometry		
Ltub	m	pipe length (per pipe)
Dtub	m	pipe diameter
ThTub	m	pipe thickness
NtubY	-	number of pipes y axis
NtubZ	-	number of pipes z axis
DsoilY	m	pipe - pipe distance y axis
DsoilZ	m	pipe - pipe distance z axis
DsoilTop	m	pipe - top surface distance
DsoilBot	m	pipe - bottom surface distance
DsoilSide	m	pipe - lateral surface distance
Node size		
DxIni	m	node initial size, x axis
DxExp	-	node expansion factor, x axis
DyzIni	m	node initial size, y and z axis
DyzExp	-	node expansion factor, y and z axis
Physical properties		
LamSoil	W/K.m	soil conductivity
CvSoil	kJ/K.m3	soil heat capacity
LamTub	W/K.m	pipe conductivity
CvTub	kJ/K.m3	pipe heat capacity
CtubFric	-	pipe friction coefficient
PrAir	Pa	air pressure
Border & initial conditions		
IsurfTop	-	border condition, top (0: adiabatic, 1: active)
RsurfTop	K.m2/W	resistance, top
AsurfTop	-	solar absorptivity
IsurfBot	-	border condition, bottom (0: adiabatic, 1: active)
RsurfBot	K.m2/W	resistance, bottom
TsurfBot	C	temperature, bottom
TiniSoil	C	initial soil temperature
Simulation		
Isim	-	type of simulation (1: typical section, 2: entire array)
Nyear	-	number of years to be simulated

Inputs and outputs

The model requires following inputs in hourly time step, on an entire year.

Variable	Unit	Description
Tin	C	inlet temperature
Hin	pcent	inlet relative humidity
Ttop	C	air temperature, top surface
Gtop	W/m2	solar radiation, top surface
Mair	m3/h	air flow (total over all pipe, even for Isim = 1)

It calculates following outputs in hourly time step.

Variable	Unit	Description
Tout	C	outlet temperature
Hout	pcent	outlet relative humidity
Psbl	kW	sensible heat rate
Plat	kW	latent heat rate
Ptop	kW	diffusive heat rate, top surface

Excel interface

The tool is embedded within an Excel 2010 interface (EP.Plus.xlsm), which serves as a platform for saving, running and loading project files. In principle, EP.Plus.xlsm remains in a specific and unique location, while the project files are stored in their individual folders (see working directory, further down).

EP.Plus.xlsm contains macros, which must be enabled when opening the workbook.

The excel workbook contains following sheets:

- ViewYear: the top part of the sheet contains the action buttons (save, run, load); below are the graphs in hourly time step over the entire year.
- ViewWeek: same as ViewYear, but with a zoom on a particular week (with slide bar for navigation within the year).
- Parameters: for definition of the parameters
- In&Outputs: for definition of the inputs, and for uploading of the outputs after the simulation.
- Zoom: inputs and outputs of the selected week.
- Miscelaneous: other stuff.

Parameters and inputs (grey-brown background) must remain between minimum and maximum values (grey-brown light background). A particular restriction goes for the airflow which, unless zero, must remain above a minimum value (numerical stability problem). This value depends on several geometry parameters (see note in corresponding cell).

Except for the editable cells (grey brown background), the cells are protected against edition, so as to protect from miss-use. If needed, the sheets may be unprotected via the review tab (under responsibility of the user).

Action buttons

There are two buttons for folder selection:

- Trnsys folder: selection/updating of the directory containing the Trnsys executable (TrnExe.exe).
- Working folder: selection of the working directory, in which the project files are stored (each project / configuration should be stored within a separate folder).

There are four buttons for saving, simulating and loading of the project files:

- Save: saves the parameters and inputs of the current project in their project files (EP.xpar.txt and EP.xin.txt).
- Run: runs the Trnsys executable (i.e. simulates the project) and creates the output file (EP.xout.txt).
- Load: loads the current project parameter, input and output files.
- Save, Run, Load: front-end treatment of the current project.

Project files

Following files are stored in the working directory:

- EP.xpar.txt: parameter file
- EP.xin.txt: input file
- EP.xout.txt: output file
- EP.dck: Trnsys configuration file (created by the simulation)
- EP.log: Trnsys log file (created by the simulation)
- EP.lst: Trnsys listing file (created by the simulation)
- EP.460: Trnsys output file concerning the air-soil heat exchanger unit, Type460 (created by the simulation)

These files should in principle not be edited outside EP.Plus.xlsx

Mathematical description

Following formulation is taken and adapted from (Hollmuller P., 2005).

Hypothesis

Following hypothesizes have been adopted:

- So as to be flexible, the orthogonal meshing allows for variable node widths in all three dimensions. Circular tubes are represented by way of equivalent square sections, lateral exchange surface being computed by way of an adequate corrective factor.
- Thermal heat diffusion is fully three dimensional. Soil characteristics are constant in time.
- Border conditions are either adiabatic or driven by a transient input. Latter can include an additional surface resistance.
- The thermal effect of the charge losses are computed in function of a friction factor, the tube surface and the air velocity. They are evenly distributed along the tubes, so that eventual singular charge losses have to be treated apart or integrated in the friction factor.

Algorithm

The model's kernel bases on the energy and mass exchanges between the airflow and the pipe. They are computed iteratively for each pipe node, from air inlet to outlet.

The energy and mass exchanges comprise following items.

- The sensible heat lost by the airflow:

  $$P_{sbl} = S_{tub} \cdot h \cdot \left(T_{air} - T_{tub}\right)$$

  The convective exchange coefficient is evaluated by way of the Nusselt number:

  $$h = \frac{\lambda_{air}}{2d} Nu$$

  which is calculated according to the Gnielinski relation:

  $$Nu = 0.0214\left(\mathrm{Re}^{0.8} - 100\right)\mathrm{Pr}^{0.4}\left(1 + \left(\frac{d}{L}\right)^{2/3}\right)\left(\frac{T_a}{T_t}\right)^{0.45}$$

- The latent heat, determined by the Lewis analogy, which actually considers former sensible heat to result from a convective air exchange between the flow and a superficial layer at pipe's temperature, the analogy implying following convective air exchange rate:

  $$\dot{m}_{conv} = \frac{P_{sbl}}{c_{air} \cdot \left(T_{air} - T_{tub}\right)}$$

Considering the air layer to be saturated in humidity, this air exchange also induces a water vapor exchange, which is determined by the difference in humidity ratios of airflow and superficial pipe layer:

$$\dot{m}_{lat} = (W_{air} - W_{tub}) \cdot \dot{m}_{conv}$$

where, according to the perfect gas equation, humidity ratios of airflow and superficial pipe layer are given by:

$$W_{air} = \frac{H \cdot \mathrm{Pr}_{sat}(T_{air}) \cdot M_{wat}}{\mathrm{Pr}_{air} \cdot M_{air}}$$

$$W_{tub} = \frac{100\% \cdot \mathrm{Pr}_{sat}(T_{tub}) \cdot M_{wat}}{\mathrm{Pr}_{air} \cdot M_{air}}$$

When positive, this vapor transfer corresponds to condensation, when negative to evaporation. In latter case it is further limited by the free water content in the considered node, as well as by the maximum humidity (saturation pressure) which can be absorbed by the airflow.

With these definitions, the associated latent heat finally writes as:

$$P_{lat} = c_{lat} \cdot \dot{m}_{lat}$$

- The heat diffusion from the 4 lateral soil nodes and the 2 preceding and following pipe nodes:

$$P_{diff} = \sum_{soil} S_i k_i (T_{soil,i,t-1} - T_{tub}) + \sum_{tube} S_i k_i (T_{tub,i,t-1} - T_{tub})$$

- The capacitive heat gain of the pipe and the free water in the node:

$$P_{int} = \frac{(c_{tub} \cdot m_{tub} + c_{wat} \cdot m_{wat,t-1}) \cdot (T_{tub} - T_{tub,t-1})}{\Delta t}$$

The saturation pressure being non-linear in terms of temperature, the pipe temperature as well as preceeding heat rates are being determined by iterative resolution of the energy balance:

$$P_{int} - (P_{sbl} + P_{lat} + P_{diff}) = 0$$

The associated hydric balance on its turn allows to determine the new water content of the node:

$$m_{wat} = m_{wat,t-1} + (\dot{m}_{inf} - \dot{m}_{lat}) \cdot \Delta t$$

Charge losses are taken in account by way of a friction coefficient f:

$$P_{fric} = \dot{m}_{air} \cdot f \cdot \frac{l}{d} \cdot \frac{v_{air}^2}{2}$$

Finally, preceding energy and mass balances yield the air input conditions of the next pipe node:

$$T_{air,i} = T_{air} + \frac{P_{fric} - P_{sbl}}{\left(c_{air} + c_{vap} \cdot W_{air}\right) \cdot \dot{m}_{air}}$$

where computation repeats in the same manner.

After completing this calculation for all tube nodes, computation treats diffusion of heat into the soil nodes, taking into account user-specified border conditions.

References

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