Heat Storage in the Ground

DUCT GROUND HEAT STORAGE MODEL

TRNSYS Version

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PARAMETER		DESCRIPTION
1	**V** -	Volume of storage region [m^3]
2	**H** -	Storage height or length of one borehole [m]
3	**DPH** -	Distance between the ground surface and the upper side of the storage volume [m]
4	**Nb** -	Number of boreholes [-]
5	**Ro** -	Outer radius of each borehole [m]
6	**NSerie** -	Number of boreholes connected in series (max. 20) [-]
7	**NRLoc** -	Number of radial subregions for the computation of the local process (NRLoc ≤ NSerie) [-]
8	**NZLoc** -	Number of vertical subregions for the computation of the local process (NZLoc*NRLoc ≤ 121) [-]
9	$\mathbf{k_s}$ -	Thermal conductivity of the storage material [kJ/h m K]
10	$\mathbf{C_s}$ -	Volumetric heat capacity of the storage material [kJ/m^3K]
11	**Rp** -	**IF Rp≥0: Rp**: thermal resistance between the fluid in the pipes and the ground at the borehole wall per unit of borehole length (fluid-to-ground therm. resist.) [K/(kJ/hm)] (x [K/(W/m)] = x / 3.6 [K/(kJ/hm)]) **IF -11≤Rp<0: -Rp**: number of U-pipes in each borehole (1 to 10); -11: coaxial pipes [-]. Rp is calculated with the help of the 9 following parameters. Rp is kept constant during the simulation. **IF Rp≤-12:** Flow- and temperature-dependent borehole thermal resistance. (-Rp) is the logical unit through which the flow- and temperature-dependent Rp values are provided. The file name should be assigned to this logical unit with an ASSIGN statement in the TRNSYS deck.

k=0

only if **-11≤Rp<0**--

12	$\mathbf{R_{po}}$ -	Pipe outer radius [m] (if coaxial, inner pipe outer radius)
13	$\mathbf{R_{pi}}$ -	Pipe inner radius [m] (if coaxial, inner pipe inner radius)
14	**D** -	U pipe axes-to-axes half distance [m]; (if coaxial pipes, outer pipe inner radius; the outer radius is the borehole radius)
15	λ_{bh} -	Thermal conductivity of borehole filling material [kJ/h m K]
16	λ_p -	Thermal conductivity of pipe material [kJ/h m K]
17	λ_{gap} -	Equivalent thermal conductivity of gap between the pipes and the filling material [kJ/h m K]
18	**Gap** -	Gap thickness (assumed existing only on half of the heat transfer surface) [m]
19	$\mathbf{V_{ref}}$ -	Reference fluid flow rate per borehole (water) for the calculation of the fluid-to-ground thermal resistance (borehole thermal resistance) [kg/h]
20	$\mathbf{T_{ref}}$ -	Reference fluid temperature (water) for the calculation of the fluid-to-ground thermal resistance [°C]

k=9

12+k	**Ra** -	**IF Ra<>0:** the heat transfers between the upward and downward fluid in the borehole are taken into account. (The concept of effective fluid-to-ground thermal resistance is used). **Ra>0:** the effective fluid-to-ground thermal resistance is calculated for the case of COAXIAL PIPES **Ra<0:** the effective fluid-to-ground thermal resistance is calculated for the case of a U-PIPE installation. **IF Rp≥0: abs(Ra)**: thermal resistance between the upward and downward fluid in the pipes (per unit of borehole length) [K/(kJ/hm)] **IF -11≤Rp<0: Ra** is calculated with the help of the 9 preceding parameters. Ra is kept constant during the simulation. Nevertheless, the sign of the parameter Ra determines the case calculated (U-pipe or not), and should be set to agree with the borehole installation. **IF Rp≤-12: Ra** is flow- and temperature-dependent. (-Rp) is the logical unit through which the Ra values are provided. **IF Ra=0:** the heat transfers between the upward and downward fluid in the borehole are NOT taken into account.
13+k	c_f -	Specific thermal capacity of the heat carrier fluid [kJ/kg K]
14+k	r_f -	Mass density of the fluid [kg/m^3]
15+k	**ISO** -	= 0 no thermal insulation [-] = 1 insulation on upper surface and side of the storage volume. An upper fraction **FRISO** of the side is covered [-] = 2 insulation only on upper surface, which extends a certain distance beyond the boundary of the storage. This distance is a fraction **FRISO** of the height of the storage [-]
16+k	**FRISO** -	Fraction of the height of the storage volume [-]
17+k	TH_{ins} -	Thickness of insulation [m]
18+k	k_{ins} -	Thermal conductivity of insulation material [kJ/h m K]
19+k	**SY** -	Number of simulation years. The numerical mesh extension depends on (increases with) this number [-]
20+k	T_{max} -	Max. temperature allowed to the storage [°C]
21+k	T_{gs} -	Initial temperature of the undisturbed ground surface [°C]
22+k	DT_g -	Initial thermal gradient in the undisturbed ground [K/m]
23+k	**IPRE** -	Number of preheating cycles (0 no pre-heating). During preheating sinusoidal yearly variation of the average storage temperature is used to heat up the surrounding ground.
24+k	$T_{max,ph}$ -	Max. uniform storage temperature during preheating cycles [°C]
25+k	$T_{min,ph}$ -	Min. uniform storage temperature during preheating cycles [°C]
26+k	**Φ**	Phase delay in preheating sinusoidal temperature curve [days]

$$T_{storage} = \frac{T_{max,ph} + T_{min,ph}}{2} + \frac{T_{max,ph} - T_{min,ph}}{2} \sin(\omega(t+\Phi))$$

N.B.: $T_{storage}(t=0)$ is taken as initial condition after preheating.

27+k	T_{ma} -	Yearly average air temperature [°C]. (For preheating calculation only)
28+k	T_{aa} -	Yearly amplitude of the air temperature [°C]. (For preheating calculation only)
29+k	Φ_{air}	Phase delay in sinusoidal air temperature curve [days] $T_{air} = T_{ma} + T_{aa} \sin(\omega(t+\Phi_{air}))$
30+k	N_l -	Number of ground layers (max. 10) [-]
31+k+(i-1)*3	k_g -	Thermal conductivity of i-th layer [kJ/h m K]
32+k+(i-1)*3	c_g -	Volumetric heat capacity of i-th layer [kJ/m^{3}K]
33+k+(i-1)*3	TH_g -	Thickness of i-th layer [m]
34+k+(N_l-1)*3	**IPRT** -	= 1 print input data, meshes coordinates and initial temperature fields. (=0 no print) [-]
35+k+(N_l-1)*3	**OPRT** -	= 1 print detailed results according the following parameters [-]
36+k+(N_l-1)*3	**LUW** -	Output logical unit for **IPRT** and/or **OPRT** special printing [-]
37+k+(N_l-1)*3	**IP1** -	= 1 print **Tair**, **Tav.stor.**, **Tin**, **Tout** and exchanged th. power during the last time step, accumulated injected energy and accumulated extracted energy until the current time, mass flow rate during the last time step. If **NSPEC** greater the zero, the temperature in **NSPEC** storage locations will be printed out. If IBLOSS equal 1, the accumulated heat losses through the storage boundaries will be printed out [-]
38+k+(N_l-1)*3	**DT1** -	Time interval between **IP1** printing [h]
39+k+(N_l-1)*3	**IP2** -	= 1 print global temperature field [-]
40+k+(N_l-1)*3	**DT2** -	Time interval between **IP2** printing [h]
41+k+(N_l-1)*3	**IP3** -	= 1 print heat flow fields [-]
42+k+(N_l-1)*3	**DT3** -	Time interval between **IP3** printing [h]
43+k+(N_l-1)*3	**IP4** -	= 1 print local temperature field [-]
44+k+(N_l-1)*3	**DT4** -	Time interval between **IP4** printing [h]
45+k+(N_l-1)*3	**IBLOSS** -	= 1 print losses through storage boundaries [-]
46+k+(N_l-1)*3	**NSPEC** -	N° of storage locations of which the temperature has to be printed out (max. 10) [-]
47+k+(N_l-1)*3+(i-1)*3	**IR** -	Node number in radial direction (global field) [-]
48+k+(N_l-1)*3+(i-1)*3	**IZ** -	Node number in vertical direction (global field) [-]
49+k+(N_l-1)*3+(i-1)*3	**IL** -	Node number in local field [-]

N.B. :

1) Parameters from 37+k+(N_l-1)*3 have to be specified only if **IPRT** or **OPRT** are greater than zero.

2) If **-11≤Rp<0** , i.e. automatic calculation of thermal resistance between the heat carrier fluid and the ground surrounding the borehole has been specified, the resulting value can be found into the DST.DAT file, if **IPRT** = 1 has been specified.

3) **NSerie** is used to determine the flow rate per borehole and to constraint the radial mesh so that NSerie radial divisions of equal volume are possible in the store.

INPUT NUMBER		DESCRIPTION
1	T_{in} -	Inlet fluid temperature [°C]
2	**m'** -	Mass flow rate [kg/h]
3	T_{airh} -	Air temperature on top of the store (i.e. house, etc.) [°C]
4	T_{air} -	Air temperature elsewhere (anywhere on ground surface except on top of the store) [°C]
5	C_{ircul} -	Switch to set the circulation of the fluid in the ground heat exchanger [-] **IF Circul>0**: the fluid circulate from subregion 1 to subregion NLoc=NRLoc*NZLoc. **IF Circul≤0**: the fluid circulate from subregion NLoc to subregion 1. If NRLoc=NZLoc=1, the switch can be set to any constant value.

Note: If NLoc=NRLoc*NZLoc>1, the first subregion is set at the center of the store (if NRLoc>1) and at the bottom (if NZLoc>1). The last subregion (NLoc) is set at the border and the top of the store. In order to provide a radial stratification of the ground temperatures in the store, the fluid should circulate from the center to the border during heat injection (Circul>0) and from the border to the center during heat abstraction (Circul≤0).

OUTPUT NUMBER		DESCRIPTION
1	T_{out} -	Outlet fluid temperature [°C]
2	**m'** -	Mass flow rate [kg/h]
3	$T_{av.st.}$ -	Average storage temperature [°C]
4	**Q'** -	Average exchanged th.power [kJ/h]
5	$Q_{loss,t}$ -	Heat losses through the top boundary of the storage [kJ/h]
6	$Q_{loss,s}$ -	Heat losses through the side boundary of the storage [kJ/h]
7	$Q_{loss,b}$ -	Heat losses through the bottom boundary of the storage [kJ/h]
8	**QDST** -	Storage internal energy variation during the last time step [kJ/h]
9	$T_{av.bh.}$ -	Average soil temperature near the boreholes (average value on the whole storage) [°C]
10	$T_{bh,1}$	Average soil temperature near the boreholes in radial subregion 1 (center)
If NRLoc≥2: 11	$T_{bh,NRLoc}$	Average soil temperature near the boreholes in radial subregion NRLoc (border)
If NRLoc≥3: 12	$T_{bh,NRLoc-1}$	Average soil temperature near the boreholes in radial subregion NRLoc-1
If NRLoc≥4:13	$T_{bh,NRLoc-2}$	Average soil temperature near the boreholes in radial subregion NRLoc-2

etc.

Note: The maximum number of output is limited to 20. The soil temperature near the boreholes in radial subregion i is an average value along the height of the store during the TRNSYS simulation time step.

Information Flow Diagram

INPUTS - 5

OUTPUTS - 10 to 9 + NRloc, maximum 20

PARAMETERS - from 35 to 112