

# **Annexe 3: BRIDGESIM, a simulation tool for the system design of bridge heating for ice prevention with solar heat stored in a seasonal ground duct store**

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### A3. The simulation tool

#### A3.1 BRIDGESIM system layout

The simulated system layout is shown in figure A3.1. Thermal simulations have shown that it is equivalent to the actual system layout of the Serso system shown in figure A3.2 (short term water tank coupled in series).

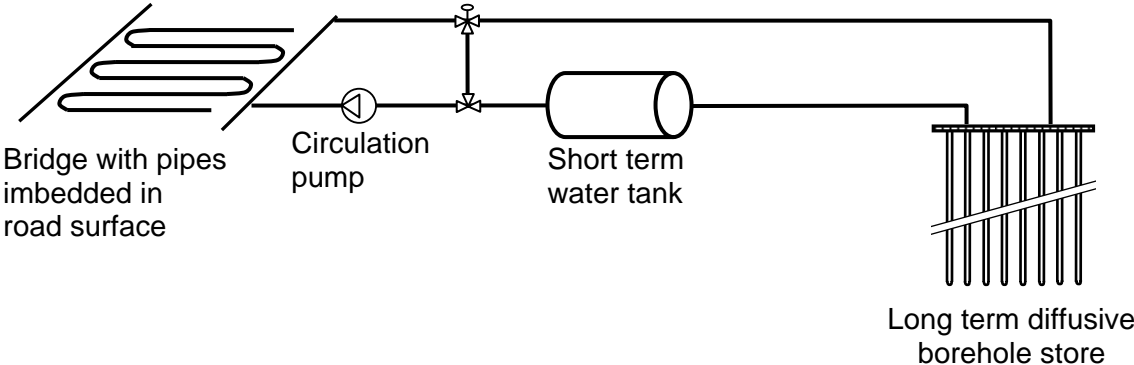


Figure A3.1 System layout simulated by the BRIDGESIM tool.

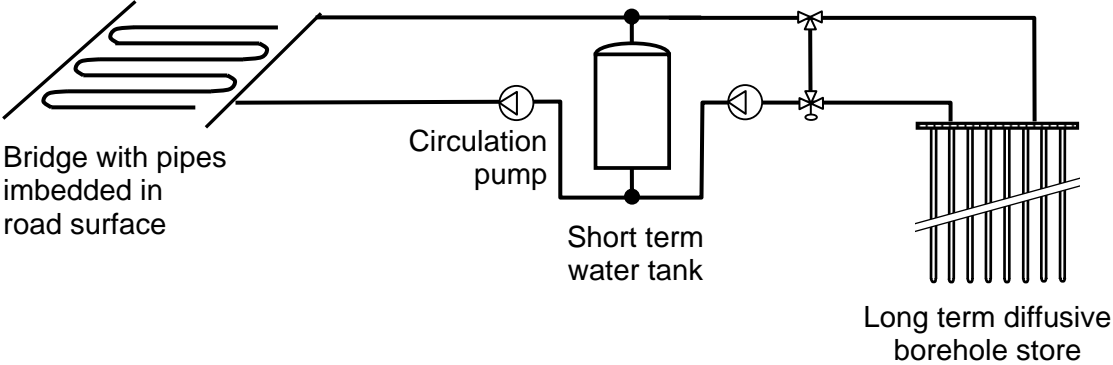


Figure A3.2 Simplified system layout of the Serso plant, equivalent to the one simulated by the BRIDGESIM tool.

#### A3.2 BRIDGESIM system control

The mixing valve is only used when the bridge is heated, in order to limit the forward fluid temperature in function of the outdoor air temperature, according to the diagram shown in figure A3.3.

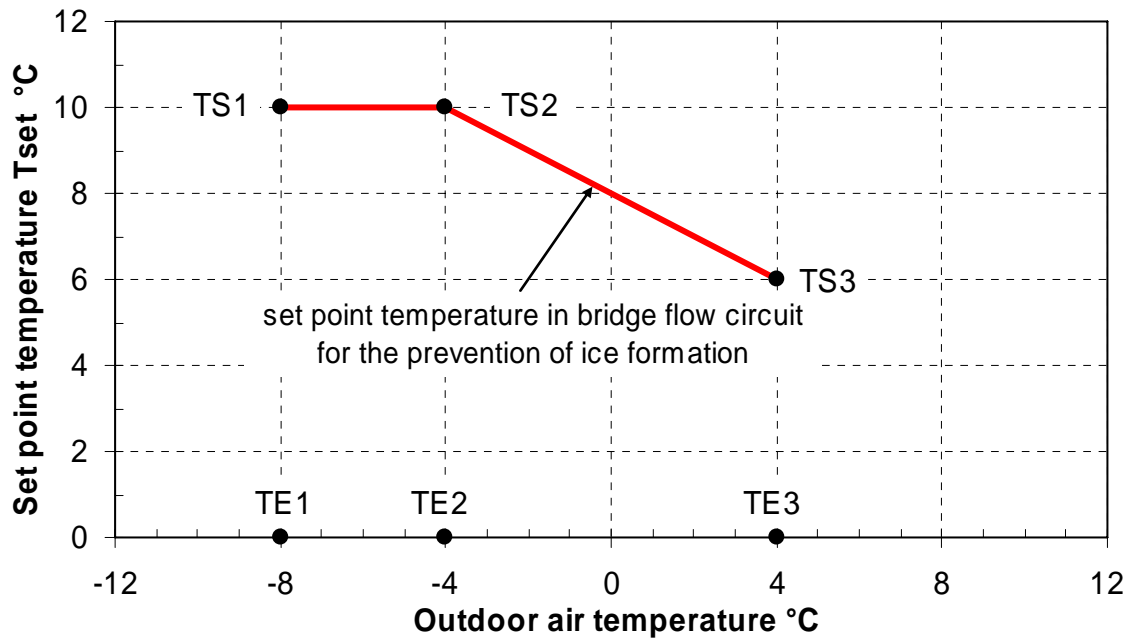


Figure A3.3 Control of the forward fluid temperature in the bridge in function of the outdoor air temperature when the system operates in the ice prevention mode (bridge heating).

Bridge heating can only be switched on when the outdoor air temperature drops below a given value, typically set to 4°C (parameter TE3).

The system operates in three different modes :

- mode « rest » : the system is stopped ;
- mode « solar collection » : the system is switched on to collect the bridge solar gains and store them in the duct ground heat storage ;
- mode « bridge unfreezing » : the system is switched on to prevent the bridge from freezing by extracting heat from the ground duct store.

Two ON/OFF controllers (TYPE2) are used to control the « solar collection » and « bridge unfreezing » modes.

**Mode « solar collection » :**

condition to switch on the system :  $T_{\text{air}} > TE3$

- |  |      |                      |
|--|------|----------------------|
| if $(T_m - T_{\text{return-fluid}}) > DT1CST$ (for example 10 K) | then | pump is switched ON  |
| if $(T_m - T_{\text{return-fluid}}) < DT0CST$ (for example 4 K)  | then | pump is switched OFF |

**Mode « bridge unfreezing » :**

condition to switch on the system :  $T_{\text{air}} > TE1$  and  $T_{\text{air}} < TE3$

- |                                   |      |                      |
|-----------------------------------|------|----------------------|
| if $(T_{\text{set1}} - T_m) > 1K$ | then | pump is switched ON  |
| if $(T_{\text{set1}} - T_m) < 0K$ | then | pump is switched OFF |

$T_m$  : bridge temperature in the plane of the imbedded pipes [ $^{\circ}\text{C}$ ] ;  
 $T_{\text{return-fluid}}$  : fluid temperature in the short term water tank, at the return pipe to the bridge [ $^{\circ}\text{C}$ ] ;  
 $T_{\text{air}}$  : outdoor air temperature [ $^{\circ}\text{C}$ ] ;  
 $T_{\text{set}}$  : set point temperature for the forward fluid temperature in the bridge (see figure 3.3) [ $^{\circ}\text{C}$ ] ;  
 $T_{\text{set1}}$  : set point temperature for  $T_m$  (see below) .

The bridge temperature in the plane of the imbedded pipes,  $T_m$ , should lie between the outdoor air temperature  $T_{\text{air}}$  and the forward fluid temperature in the bridge  $T_{\text{set}}$ . As the thermal resistance to the fluid temperature is significantly smaller than that to the outdoor air temperature,  $T_{\text{set1}}$  should be close to  $T_{\text{set}}$ . On the basis of estimations and for commodity,  $T_{\text{set1}}$  is defined with the following relation:

$$T_{\text{set1}} = TS3 + 0.75 (T_{\text{set}} - TS3)$$

In the calibrated model (see annex 2), the temperature  $T_{\text{set1}}$  was fixed to  $4^{\circ}\text{C}$ .

### **A3.3 BRIDGESIM system simulation tool**

The simulation models used in BRIDGESIM are described in annex 1 and 2. The use of BRIDGESIM require to define first the set point temperature curve, as shown in figure A3.3, to heat the bridge. In other terms, the heat delivered using the heating curve, assuming that the set point temperature is always met, has to keep the bridge surface free from ice with the minimum amount of thermal energy necessary. To help determine the heating curve, the tool BRIDGEHEAT has been created, which is a simplified version of BRIDGESIM. The input data to BRIDGEHEAT are the same as those for BRIDGESIM, except for the non necessary components, such as the ground duct store. In the next section, the input data to BRIDGESIM are listed.

### **A3.4 Input data to BRIDGESIM**

The input data to BRIDGESIM concern all the information that can be varied by the user. In particular, the input data define the size and characteristics of the different parts of the system and the driving conditions which will condition the operation of the system. In this chapter, each parameter required to BRIDGESIM is described and explained.

The input data are grouped in 9 blocks:

- simulation parameters
- weather parameters
- bridge parameters
- duct store parameters
- ground parameters

- water tank parameters
- circulation pump parameter
- heating curve parameters
- solar controller parameters

The BRIDGEHEAT tool, used to determine the heating curve, only requires the input data of the three blocks “weather parameters”, “bridge parameters” and “heating curve parameters”.

BRIDGESIM and BRIDGEHEAT are TRNSED applications. The input parameter values may either be given in the “primary units”, which correspond to the unit assumed by TRNSYS, or in the “secondary units”, which are more convenient units for the user. For example, the primary unit of a thermal conductivity is normally [kJ/(h m K)], whereas the secondary unit is [W/(mK)]. All the units given in the following sections for the input parameters correspond to the “secondary units”. When BRIDGESIM or BRIDGEHEAT are used, it is highly recommended to set the units on “secondary”. This is done by selecting *Secondary Units* in the menu *TRNSYS* of the TRNSED application.

#### A3.4.1 Simulation parameters

The five entries related to these parameters are:

**Month for simulation start:** the simulation starts the first day of the chosen month.

**Length of simulation:** duration of the simulation period. The maximum duration is limited to 25 years if the simulation starts in January. If the simulation starts another month, the maximum duration is shorter, as the maximum of 25 years is counted from January of the first operational year.

**Time interval for output results:** quantities can be calculated on a monthly basis or a yearly basis. They are integrated heat rates or average values. See chapter 5 for a complete description of the output results.

**Calculate temperature levels with inlet-outlet average:** this parameter determines if the average temperature levels are calculated with the inlet-outlet means in bridge and store (yes) or not (no).

**Print hourly values for last year:** this parameter determines if the hourly values of some selected quantities are written (yes) or not (no) for the last operational year (see chapter 5 for more details).

#### A3.4.2 Weather parameters

The four entries are:

**Latitude of the location:** the latitude of the location where the project is evaluated [°].

**Longitude of the location:** the longitude of the location where the project is evaluated [°] (East is negative).

**Altitude of the location:** the altitude of the location where the project is evaluated [m].

**Weather data file (look in BridgeData directory):** this file contains weather data on a hourly basis of the location where the project is evaluated. The weather data files are grouped in the BRIDGEDATA directory. The weather file to be chosen has the extension .PIL. This is a listing file containing the key word FILES on the first line, followed by the path name of the data file (with the extension .TXT), repeated 25 times on the next lines.

For example, weather data contained in the WEATHER.TXT file require the creation of a WEATHER.PIL file in the BRIDGEDATA directory. The WEATHER.PIL file is a text file that contains:

```
FILES  
bridgedata\weather.txt  
bridgedata\weather.txt  
...  
bridgedata\weather.txt
```

The weather data file, with the extension .TXT, contains hourly values of one year meteorological data. The first line must correspond to the first hour of the year. Each line must contain, in the order given below, the following quantities separated by a space or a tab character. It can be created with the programme METEON 5.0 (XXXRemund J. und Kunz S., 2003), using the “user defined” format:

- hour of the year [-];
- global horizontal radiation [ $\text{W}/\text{m}^2$ ];
- diffuse horizontal radiation [ $\text{W}/\text{m}^2$ ];
- global radiation in the tilted plane [ $\text{W}/\text{m}^2$ ];
- diffuse radiation in the tilted plane [ $\text{W}/\text{m}^2$ ];
- normal beam radiation [ $\text{W}/\text{m}^2$ ];
- outdoor air temperature [ $^{\circ}\text{C}$ ];
- relative humidity of the air [%];
- dew point temperature [ $^{\circ}\text{C}$ ];
- cloud cover fraction [-].

The tilted plane is the horizontal plane (azimuth :  $0^{\circ}$  and inclination :  $0^{\circ}$ ), but with the effect of the far horizon. In Switzerland, it can be calculated by METEON with the site coordinate (latitude, longitude and altitude).

#### A3.4.3 Bridge parameters

The 14 entries are:

**Bridge area to unfreeze (SROAD):** area of the bridge surface that is equipped with pipes for heating and solar gains collection [ $\text{m}^2$ ].

**Bridge area defined in PREBID input file:** area of the bridge surface that is defined in PREBID, the TRNSYS programme editor for the building model TYPE 56 used to model the bridge. This area should be as close as possible as SROAD and must correspond to the area defined in PREBID output files for the bridge definition [m<sup>2</sup>].

**PREBID file containing bridge description (for building TYPE 56) (\*.BLD):** PREBID output file \*.BLD that contains the bridge description. This file should be stored in the BRIDGEDATA directory.

**Associated file containing the transfer function information (\*.BLD):** PREBID output file \*.TRN associated to the \*.BLD file that contains the transfer function information. This file should be stored in the BRIDGEDATA directory, together with the \*.BLD file.

**Spacing between the imbedded pipes in the bridge surface (BPIPE):** average distance between two parallel pipes of the bridge surface [m].

**Outer diameter of the imbedded pipes (DEXTPIPE):** outer diameter of the pipes that are imbedded in the bridge surface [mm].

**Inner diameter of the imbedded pipes (DINTPIPE):** inner diameter of the pipes that are imbedded in the bridge surface [mm].

**Thermal conductivity of the pipe material (LPIP):** thermal conductivity of the material used for the pipes imbedded in the bridge surface [W/(mK)].

**Thermal conductivity of the material in which the pipes are imbedded:** thermal conductivity of the material layer in which the pipes are imbedded. It must correspond to the value used in BREPID for the bridge definition [W/(mK)].

**Thermal conductivity of the heat carrier fluid:** thermal conductivity of the fluid that circulates in the pipes [W/(mK)].

**Nusselt number for the convective heat transfer from the fluid to the pipe wall (NUFLUID):** a constant number is given for the convective heat transfer from the heat carrier fluid to the inner pipe wall and is defined here [-].

**Fluid flow rate per square meter of heated bridge surface (FLOWSPEC):** it is the total nominal flow rate flowing through the bridge divided by the heated bridge surface SROAD [litre/(h m<sup>2</sup>)].

**Heat carrier fluid density:** density of the heat carrier fluid that circulates in the imbedded pipes [kg/m<sup>3</sup>].

**Heat carrier fluid heat capacity:** specific heat capacity of the heat carrier fluid that circulates in the imbedded pipes [kJ/(kg K)].

#### A3.4.4 Duct store parameters

The 19 entries are:

**Diameter of borehole heat exchanger (BHE) type 1 (DP1):** diameter of the borehole for the BHE type 1 [m].

**Number of BHE type 1 (N1):** number of borehole heat exchangers for the type 1 [-].

**Average active length of BHE type 1 (H1):** average length of the borehole heat exchangers of type 1. The active length of a BHE is defined by the bore length for which a radial heat transfer with the ground may occur. In other terms, it is the length of the borehole that is equipped with pipes [m].

**Thermal resistance of BHE type 1 (RB1):** thermal resistance of BHE type 1. The thermal resistance of a pile determines the temperature difference between the fluid and the ground in the immediate vicinity of the pile under a given heat transfer rate. A typical value for a double U-pipe BHE is 0.1 K/(W/m). Such a value will induce a temperature difference of 5 K between the fluid temperature and the ground temperature at the borehole border, when a heat transfer rate of 50 W/m takes place in steady flux conditions in the BHE [K/(W/m)].

**Internal thermal resistance of BHE type 1 (RA1):** internal thermal resistance of BHE type 1. A typical value for a double U-pipe BHE is 0.4 [K/(W/m)].

**Diameter of BHE type 2:** diameter of the borehole for the BHE type 2 [m].

**Number of BHE type 2:** number of borehole heat exchangers for the type 2 [-].

**Average active length of BHE type 2:** average length of the borehole heat exchangers of type 2 [m].

**Thermal resistance of BHE type 2:** thermal resistance of BHE type 2 [K/(W/m)].

**Internal thermal resistance of BHE type 2:** internal thermal resistance of BHE type 2 [K/(W/m)].

**Average spacing between the BHE (BBORE):** average spacing of all the BHE in the two spatial directions of the ground area that contains the BHE [m].

**Pipe number in a cross section of a BHE:** number of pipes in a cross section of the BHE. For a double U-pipe BHE, the number of pipes is 4 [-].

**Inner diameter of one pipe:** average inner diameter of the pipe used inside the BHE [m].

**Number of BHE coupled in series (NSERIE):** number of BHE coupled in series. It defines the hydraulic coupling of the BHE, and thus the flow rate per BHE. The series of BHE are supposed to be coupled in the radial direction of the store, from the centre to the border [-].

**Length of the horizontal pipes on top of the duct store (LCOEPF):** the length of the horizontal pipes on ground is the effective pipe length that connects the BHE to the pipe collectors. This parameter is used for the determination of the heat transfer that occurs between the fluid in these pipes and the ground in the plane of the pipes. The pipes are supposed to lie below the insulation layer on top of the store if any [m].

**Insulation thickness on top of the duct store (DISO):** thickness of the insulation layer on top of the store if any [m].

**Thermal conductivity of the insulation material (LISO):** thermal conductivity of the insulation material [W/(m K)].

**Horizontal extension of the insulation layer given as a fraction of the store depth (FRISO):** the insulation layer on top of the store may extend beyond the store boundary. FRISO give the radial extension of the insulation layer as a fraction of the store depth (the store vertical extension) [-].

**Earth layer thickness covering the duct store (DHP):** thickness of the earth layer that may cover the top of the store and the insulation layer if any [m].

#### *A3.4.5 Ground parameters*

Up to 3 different horizontal ground layers can be specified. A ground layer is defined by its thickness, the thermal conductivity and volumetric heat capacity of the ground and the Darcy velocity of the water contained in the ground layer.

The 16 entries are:

**Mean undisturbed ground temperature at the surface (TGRDIN):** initial temperature of the ground before the construction of the borehole field. This temperature should be close to the annual average value of the ground near the surface. A rough estimation is to use the mean annual air temperature at the surface plus about 1 K [°C].

**Mean temperature gradient in the undisturbed ground (DTGRND):** geothermal temperature gradient, assumed to be constant. It defines the temperature increase of the ground with the depth [K/km].

**Thermal conductivity of ground layer 1 (LG1):** thermal conductivity of ground layer 1 [W/(mK)].

**Volumetric thermal capacity of ground layer 1 (CG1):** volumetric thermal capacity of ground layer 1 [MJ/(m<sup>3</sup>K)].

**Thickness of ground layer 1 (HG11):** thickness of ground layer 1. Ground layer 1 must be larger than 0.3m, the thickness of ground layer 0 that lies on top of ground layer 1. Ground layer 0 is a pre-defined ground layer in which lie the horizontal pipes that connect the BHE to the system [m].

**Darcy velocity of ground water in layer 1 (DA1):** Darcy velocity of the ground water in the ground layer 1. This parameter determines the forced convection in ground layer 1 due to a horizontal regional ground water flow. A zero value means no forced convection [m/day].

The Darcy velocity (in m/s) can be obtained by the product of the ground layer permeability (in m/s) times the horizontal hydraulic gradient of the regional ground water flow (in m/m).

NB: only a direct thermal interaction with the BHE is computed. In other terms, if the ground layer lies below the bottom of the piles, the effect of a regional ground water flow will not be computed. If only the upper part of ground layer is crossed by the BHE, the effect will be computed in the upper part only. The thermal influence will be then propagated upwards and downwards by pure heat conduction.

NB: the full influence of a ground water flow is only calculated if the two last parameters from the ground parameter block are switched to “YES”.

**Thermal conductivity of ground layer 2 (LG2):** thermal conductivity of ground layer 2 [W/(mK)].

**Volumetric thermal capacity of ground layer 2 (CG2):** volumetric thermal capacity of ground layer 2 [MJ/(m<sup>3</sup>K)].

**Thickness of ground layer 2 (HG2):** thickness of ground layer 2 [m].

**Darcy velocity of ground water in layer 2 (DA2):** Darcy velocity of the ground water in the ground layer 2. This parameter determines the forced convection in ground layer 2 due to a horizontal regional ground water flow. A zero value means no forced convection [m/day].

**Thermal conductivity of ground layer 3 (LG3):** thermal conductivity of ground layer 3 [W/(mK)].

**Volumetric thermal capacity of ground layer 3 (CG3):** volumetric thermal capacity of ground layer 3 [MJ/(m<sup>3</sup>K)].

**Thickness of ground layer 3 (HG3):** thickness of ground layer 3. The thickness ground layer 3, which is the lowest ground layer, is supposed to extend downward as far as necessary by the thermal calculations [m].

**Darcy velocity of ground water in layer 3 (DA3):** Darcy velocity of the ground water in the ground layer 3. This parameter determines the forced convection in ground layer 3 due to a horizontal regional ground water flow. A zero value means no forced convection [m/day].

**Simulate forced convection on global process:** this parameter determines if the global effect of the forced convection is taken into account (see below).

YES: global effect of forced convection taken into account;

NO: global effect of forced convection not taken into account.

**Simulate forced convection on local process:** this parameter determines if the local effect of the forced convection is taken into account (see below).

YES: local effect of forced convection taken into account;

NO: local effect of forced convection not taken into account.

The effect of forced convection is treated as the superposition of two effects:

- **the global process:**  
a heat balance of the heat transfer by forced convection is performed on the boundary of the ground volume that is ascribed to the heat exchanger piles. The heat quantity transferred by forced convection to or from the ground volume is treated as a global temperature change of the ground temperature in the volume. The global process takes into account long term effects, which, in particular, determine the magnitude of a natural thermal recharge of the ground by a regional ground water flow.
- **the local process:**  
for the case of pure heat conduction, a temperature gradient takes place around the heat exchanger piles when they are used to transfer heat with the ground. As a result, the heat transfer is limited by the presence of a local temperature difference between the piles and the mean ground temperature. If ground water flows across the piles, the temperature field will be shifted. For a sufficiently large flow, the local temperature difference will be decreased and the heat transfer between the piles and the ground improved. The local process takes into account the improvement of this heat transfer.

#### *A3.4.6 Water tank parameters*

The 4 entries are:

**Water tank volume (VOLTANK):** water volume of the short term water tank coupled between the bridge flow loop and the duct store flow loop [ $\text{m}^3$ ].

**Water tank surface (STANK):** area of the water tank through which heat losses with the ambient take place [ $\text{m}^2$ ].

**Water tank heat loss coefficient (HTANK):** average heat loss coefficient of the water tank [ $\text{W}/(\text{m}^2\text{K})$ ].

**Mean ambient temperature around the water tank (TAIRTANK):** mean ambient air temperature in which stand the water tank. A mean constant value is assumed [ $^{\circ}\text{C}$ ].

#### *A3.4.7 Circulation pump parameter*

The only entry is:

**Total nominal electric power of the circulation pumps (PELPUMP):** total electric power absorbed by all the circulation pumps of the system. Simulations have shown that if the bridge circulation pump is operating, so is the duct store one and vice versa. As a constant flow rate is simulated, the electric energy consumed by the circulation pumps is simply the product of the total electric power by the system operation time [kW].

#### A3.4.8 Heating curve parameters

The five entries correspond to TE1, TE2, TE3, TS2 and TS3 of figure A3.3. TS1 does not need to be entered as its value is set to TS2.

**Outdoor air temperature below which the bridge surface is heated (TE3):** outdoor air temperature below which the bridge is heated [°C].

**Corresponding set point for the forward fluid temperature in the bridge (TS3):** set value of the forward fluid temperature to the bridge, when the outdoor air temperature is equal to TE3 [°C].

**Outdoor air temperature below which the forward fluid temperature is constant (TE2):** outdoor air temperature below which the forward fluid temperature is constant [°C].

**Corresponding set point for the forward fluid temperature in the bridge (TS2):** set value of the forward fluid temperature to the bridge, when the outdoor air temperature is equal to TE2. When the air temperature is between TE2 and TE3, the forward fluid temperature is linearly interpolated between TS2 and TS3 in function of the air temperature [°C].

**Outdoor air temperature limit below which bridge heating is stopped (TE1):** outdoor air temperature below which bridge heating is stopped. Between TE1 and TE2, the forward fluid temperature is constant and set to TS2 [°C].

#### A3.4.9 Solar controller parameters

The 2 entries are:

**Higher dead band temperature for the solar heat controller (DT1CST):** higher dead band temperature for the solar heat controller. The temperature difference between the average bridge temperature in the imbedded pipe plane and the outlet fluid from the water tank has to be greater than DT1CST before the circulation pump can be switched on to collect solar gains [K].

**Lower dead band temperature for the solar heat controller (DT0CST):** lower dead band temperature for the solar heat controller. The temperature difference between the average bridge temperature in the imbedded pipe plane and the outlet fluid from the water tank has to be smaller than DT0CST before the circulation pump is switched off to stop collecting solar gains [K].

### A3.5 How to run BRIDGESIM

Once the data are defined as desired, it is recommended to save the data before a simulation is started. The input data are saved in the file BRIDGESIM.TRD. It is done in the *File / Save* menu of the TRNSED programme. A simulation is started in the menu *TRNSYS / Calculate*. A series of simulations can also be defined and then simulated. The user is advised to read the help provided with the TRNSED programme. It is found in the menu *Help / TRNSED Help*, and then look for the topic *Parametrics Menu*).

When a series of simulations is performed, a *New Table* is created in the menu *Parametrics*. All the parameters that can be varied are listed. The user selects the desired parameter to be varied and defines the ranges of variations. The units of the parameters must correspond to the primary units. In table A3.1 are listed all the parameter that can be varied, together with their primary units.

Parameter	Short description	Primary unit	= sec. unit x factor
BBORE	Average spacing between the BHE (Borehole Heat Exchanger)	m	= m
BPIPE	Spacing between the imbedded pipes in the bridge	m	= m
CG1	Volumetric heat capacity of ground layer 1	kJ/(m <sup>3</sup> K)	= MJ/(m <sup>3</sup> K) x 1000
CG2	Volumetric heat capacity of ground layer 2	kJ/(m <sup>3</sup> K)	= MJ/(m <sup>3</sup> K) x 1000
CG3	Volumetric heat capacity of ground layer 3	kJ/(m <sup>3</sup> K)	= MJ/(m <sup>3</sup> K) x 1000
DA1	Darcy velocity of ground water in layer 1	m/s	= m/day x (1/86'400)
DA2	Darcy velocity of ground water in layer 2	m/s	= m/day x (1/86'400)
DA3	Darcy velocity of ground water in layer 3	m/s	= m/day x (1/86'400)
DEXTPIPE	Outer diameter of the imbedded pipes	m	= mm x (1/1'000)
DHP	Earth layer thickness covering the duct store	m	= m
DINTPIPE	Inner diameter of the imbedded pipes	m	= mm x (1/1'000)
DISO	Insulation thickness on top of the duct store	m	= m
DP1	Diameter of BHE type 1	m	= m
DT0CST	Lower dead band temperature for the solar controller	K	= K
DT1CST	Higher dead band temperature for the solar controller	K	= K
DTGRND	Mean temperature gradient in the undisturbed ground	K/m	= K/km x (1/1'000)

Table A3.1 List of the parameters that can be varied in a multiple simulation

Parameter	Short description	Primary unit	= sec. unit x factor
FLOWSPEC	Fluid flow rate per square meter of heated bridge surface	litre/(h m <sup>2</sup> )	= litre/(h m <sup>2</sup> )
FRISO	Horizontal extension of the insulation layer given as a fraction of store height	-	= -
H1	Average active length of BHE type 1	m	= m
HG11	Thickness of ground layer 1	m	= m
HG2	Thickness of ground layer 2	m	= m
HG3	Thickness of ground layer 3	m	= m
HTANK	Water tank heat loss coefficient	kJ/(h m <sup>2</sup> K)	= W/(m <sup>2</sup> K) x 3.6
LCOEPF	Length of the horizontal pipes on top of the duct store	m	= m
LG1	Thermal conductivity of ground layer 1	kJ/(h m K)	= W/(mK) x 3.6
LG2	Thermal conductivity of ground layer 2	kJ/(h m K)	= W/(mK) x 3.6
LG3	Thermal conductivity of ground layer 3	kJ/(h m K)	= W/(mK) x 3.6
LISO	Thermal conductivity of the insulation material	kJ/(h m K)	= W/(mK) x 3.6
LPIP	Thermal conductivity of the pipe material	W/(mK)	= W/(mK)
N1	Number of BHE type 1	-	= -
NSERIE	Number of BHE coupled in series	-	= -
NUFLUID	Nusselt number for the convective heat transfer from the fluid to the pipe wall	-	= -
PELPUMP	Total nominal electric power of the circulation pumps	kJ/h	= kW x 3'600
RA1	Internal thermal resistance of BHE type 1	K/(kJ/hm)	= K/(W/m) x (1/3.6)
RB1	Thermal resistance of BHE type 1	K/(kJ/hm)	= K/(W/m) x (1/3.6)
SROAD	Heated bridge area	m <sup>2</sup>	= m <sup>2</sup>
STANK	Water tank surface	m <sup>2</sup>	= m <sup>2</sup>

Table A3.1 List of the parameters that can be varied in a multiple simulation (continued)

Parameter	Short description	Primary unit	= sec. unit x factor
TAIRTANK	Mean ambient temperature around the water tank	°C	= °C
TE1	Outdoor air temperature limit below which bridge heating is stopped	°C	= °C
TE2	Outdoor air temperature below which the forward fluid temperature is constant	°C	= °C
TE3	Outdoor air temperature below which bridge heating is allowed	°C	= °C
TGRDIN	Mean undisturbed ground temperature at the surface	°C	= °C
TS2	Set point fluid temperature in bridge at TE2 (normally is the maximum value)	°C	= °C
TS3	Set point fluid temperature in bridge at TE3 (normally is the minimum value)	°C	= °C
VOLTANK	Water tank volume	m <sup>3</sup>	= m <sup>3</sup>

Table A3.1 List of the parameters that can be varied in a multiple simulation (continued)

If a parametric study is performed with the borehole parameters (RB1, RA1, N1, H1), it is best to define only one type of BHE.

A multiple simulation is started once a parameter table has been created, using the command *Run Table* in the menu *TRNSYS*.

### A3.6 Output data from BRIDGESIM

The output data from BRIDGESIM are written in four different files. Two files contain the input information given to BRIDGESIM and possible error messages, and two files contains the calculated quantities by BRIDGESIM. Assuming that the file containing the input data is called BRIDGESIM.TRD, the following files are written:

- BRIDGESIM.LST (listing file)
- DST.DAT (input data related to TRNVDSTP)
- BRIDGESIM.OUT (output data, calculated parameters, integrated quantities)
- BRIDGESIM.PLT (output data, evolution of selected variables)

After a simulation, the file BRIDGESIM.LST can be viewed in the *Windows* menu of the TRNSED programme, and the files BRIDGESIM.OUT in the *Windows / Output* menu. A plot can be made with the file BRIDGESIM.PLT and viewed in the *Plot* menu. The file DST.DAT can be viewed in the *File / Open* menu. The file name DST.DAT has to be entered in the *File name* field of the dialogue box which popped on the screen. (An error message will then appear, as DST.DAT is supposed to be a TRNSED file. However, it is still possible to view the file).

### A3.6.1 The Listing File *BRIDGESIM.LST*

This is the listing file written by TRNSYS. All the information contained in BRIDGESIM.TRD is written in the listing file, together with some information related to the simulation itself (simulation duration, total number of call for each component, warning message if any, etc.). It should be noted that if an error makes a simulation to abort, the corresponding error message is written at the end of the listing file. It is recommended to read this file every time a simulation is terminated with an error.

### A3.6.2 The File *DST.DAT*

This file is written by the TRNVDSTP component which simulates the borehole heat exchanger field. It contains all the parameter used by this component, together with information on the fields used for the simulation of the heat transport in the ground.

### A3.6.3 The Output File *BRIDGESIM.OUT*

This file starts with some of the mean parameter values which are calculated and used for the simulation. They are:

<b>NEPF</b>	[-] : total number of borehole heat exchangers.
<b>HEPF</b>	[m] : average active pile length of all the borehole heat exchangers.
<b>BBore</b>	[m]: average spacing between the borehole heat exchangers.
<b>FloEPF</b>	[kg/h] : total mass flow rate through the bridge and the duct store flow circuits.
<b>SRoad</b>	[m <sup>2</sup> ] : total heated bridge area.
<b>VolTank</b>	[m <sup>3</sup> ]: short term water tank volume.
<b>FLMEAN</b>	[-]: parameter for average inlet – outlet (FLMEAN=1) or not (FLMEAN=0) when the mean temperature levels are computed.

Maximum or minimum values of some selected quantities are calculated on a regular time interval (month or year).

<b>PMaxSolBri</b>	[kW]: maximum hourly heat power recovered from the bridge (solar heat power).
<b>PMaxLoaDST</b>	[kW]: maximum hourly heat power injected into the ground duct store.
<b>PMinUnload</b>	[kW]: as extracted heat is negative, the minimum corresponds to the maximum hourly heat power extracted from the ground duct store.
<b>PMinHeatBr</b>	[kW]: as heating energy delivered to the bridge is negative, the minimum corresponds to the maximum hourly heat power injected into the bridge.
<b>TfMinStk</b>	[degree C]: minimum inlet fluid temperature in the ground duct store during operation.
<b>TfMaxStk</b>	[degree C]: maximum inlet fluid temperature in the ground duct store during operation.

Integrated or average quantities of various quantities are calculated on a regular time interval (month or year). They are produced with the help of 6 simulation summary type components. The labels of each calculated quantity are explained below for each of the simulation summary.

**First simulation summary:**

<b>Qsolar</b>	[kWh]: incident solar radiation on bridge surface.
<b>QSolBridge</b>	[kWh]: collected solar heat from bridge.
<b>QLoadStk</b>	[kWh]: stored heat in ground duct store.
<b>QLossStk</b>	[kWh]: duct store heat losses.
<b>QEDSTin</b>	[kWh]: duct store stored energy (variation of its internal energy).
<b>QUnloadStk</b>	[kWh]: recovered heat from ground duct store.
<b>QHeatBridg</b>	[kWh]: heating energy injected into the bridge.
<b>QLossTank</b>	[kWh]: heat losses from the short term water tank.
<b>QElecLoad</b>	[kWh]: circulation pump electric energy for solar gain collection.
<b>QElecUnloa</b>	[kWh]: circulation pump electric energy for bridge heating.

A system heat balance can be performed with the following relation:

$$\mathbf{QSolBridge = QLossTank + QHeatBridg + QLossStk + QEDSTin}$$

**Second simulation summary:**

<b>QSolBridge</b>	[kWh]: collected solar heat from bridge (only positive values).
<b>TSolBridge</b>	[°C]: temperature level of the outlet fluid from the bridge when solar gains are collected (in the case FLMEAN = 0). If FLMEAN = 1, the temperature level is the average inlet – outlet.
<b>QLoadStk+</b>	[kWh]: stored heat in duct store (only positive values).
<b>TLoadStk</b>	[°C]: temperature level of the inlet fluid in the duct store when the duct store is loaded (in the case FLMEAN = 0). If FLMEAN = 1, the temperature level is the average inlet – outlet.
<b>TmDST</b>	[°C]: mean duct store temperature.
<b>QUnloadStk</b>	[kWh]: recovered heat from duct storage (only negative values).
<b>TUnloadStk</b>	[°C]: temperature level of the outlet fluid from the duct store when the duct store is unloaded (in the case FLMEAN = 0). If FLMEAN = 1, the temperature level is the average inlet – outlet.
<b>QHeatBridg</b>	[kWh]: heating in bridge (only negative values).
<b>THeatBridg</b>	[°C]: temperature level of the inlet fluid in the bridge when the bridge is heated (in the case FLMEAN = 0). If FLMEAN = 1, the temperature level is the average inlet – outlet.
<b>TAirExtM</b>	[°C]: mean outdoor air temperature.

### Third simulation summary:

<b>tload</b>	[h]: duration of the system loading operation (solar collection duration).
<b>tunload</b>	[h]: duration of the system unloading operation (bridge heating duration).
<b>HHorTot</b>	[kWh/m <sup>2</sup> ]: total incident solar radiation on bridge surface per square meter.
<b>SolEff</b>	[%]: solar heat collection efficiency of the bridge (QSolBridge/QSolar).
<b>DuctEff</b>	[%]: duct store efficiency (-QUnloadStk/QLoadStk).
<b>EffSys</b>	[-]: system efficiency (-QHeatBridg/(QElecLoad+QElecUnloa)).
<b>QLoadSpe</b>	[kWh/m]: injected energy in duct store per meter borehole heat exchanger.
<b>PLoadSpe</b>	[W/m]: mean injected power in duct store per meter borehole heat exchanger.
<b>QUnloadSpe</b>	[kWh/m]: extracted energy from duct store per meter borehole heat exchanger.
<b>PUnloadSpe</b>	[W/m]: mean extracted power from duct store per meter borehole heat exchanger.

### Fourth simulation summary:

<b>TBSol</b>	[°C]: temperature level of the inlet fluid in the bridge when the solar gains are collected (in the case FLMEAN = 0). If FLMEAN = 1, the temperature level is the average inlet – outlet.
<b>QBSol</b>	[kWh]: collected solar heat from bridge.
<b>TBHeat</b>	[°C]: temperature level of the outlet fluid from the bridge when the bridge is heated (in the case FLMEAN = 0). If FLMEAN = 1, the temperature level is the average inlet – outlet.
<b>QBHeat</b>	[kWh]: heating energy injected into the bridge.
<b>QLosses</b>	[kWh]: water tank thermal losses (>0 losses; <0 gains).
<b>TSLoad</b>	[°C]: temperature level of the outlet fluid from the ground duct store when the store is loaded (in the case FLMEAN = 0). If FLMEAN = 1, the temperature level is the average inlet – outlet.
<b>QSLoad</b>	[kWh]: stored heat in ground duct store.
<b>TSUnload</b>	[°C]: temperature level of the inlet fluid in the ground duct store when the store is unloaded (in the case FLMEAN = 0). If FLMEAN = 1, the temperature level is the average inlet – outlet.
<b>QSUnload</b>	[kWh]: recovered heat from ground duct store.
<b>ErrSys</b>	[%]: error in percent of the system heat balance. The system heat balance is calculated with:

$$\mathbf{QBSol - QBHeat - QSLoad + QSUnload - QLosses - \delta Q = 0}$$

deltaQ is the variation of the internal energy of the water tank

**Fifth simulation summary:**

<b>TTop</b>	[°C]: mean road surface temperature.
<b>TBot</b>	[°C]: mean "under" bridge surface temperature.
<b>TSurfi</b>	[°C]: mean surface temperature of inner surfaces of the fictive zone for the simulation of the pipes in the bridge. It corresponds to the mean bridge temperature in the plane of the imbedded pipes.
<b>TAirZon</b>	[°C]: mean air temperature of fictive zone for the simulation of the pipes in the bridge. Type56 parameters should be set so that TAirZon is quasi equal to TSurfi).
<b>QRoad</b>	[kWh]: thermal energy transferred through the road surface.
<b>QUnder</b>	[kWh]: thermal energy transferred through the "under" bridge surface.
<b>QAbsO</b>	[kWh]: solar energy absorbed in the road surface.
<b>QStored</b>	[kWh]: thermal energy stored in the bridge structure (+ stored; - unstored).
<b>QExFl</b>	[kWh]: thermal energy exchanged by pipes imbedded in the bridge.
<b>Error</b>	[%]: error in percent of the fictive zone heat balance. The fictive zone heat balance is calculated with:

$$Q_{siTop} + Q_{siBot} - Q_{exFl} = 0$$

QsiTop is the thermal energy flowing from the pipe plane to the road surface;

QsiBot is the thermal energy flowing from the pipe plane to the "under" bridge surface

**Sixth simulation summary:**

<b>QDstToGrd</b>	[kWh]: energy transferred to the ground by the vertical borehole heat exchangers.
<b>QPipToGrd</b>	[kWh]: energy transferred to the ground by the horizontal pipe connections.
<b>QLossOut</b>	[kWh]: total heat losses from the duct store.
<b>QEDSTIN</b>	[kWh]: duct store stored energy (variation of its internal energy).
<b>ERRDS%</b>	[%]: error on the duct store heat balance calculation.
<b>TmCenter</b>	[°C]: mean borehole temperature in ground duct store centre.
<b>TmBorder</b>	[°C]: mean borehole temperature in ground duct store border.
<b>QLossTout</b>	[kWh]: heat losses through the ground duct store top side.
<b>QLossSout</b>	[kWh]: heat losses through the ground duct store vertical sides.
<b>QLossBout</b>	[kWh]: heat losses through the ground duct store bottom side.

### A3.6.4 The Plot File PILESIM.PLT

This file contains the time evolution of some temperatures and heat rates for the last year of the simulation period. Hourly values of these quantities are written in this file only if the input parameter “Print hourly values for last year” is set to “Yes”. Their labels are explained below. The 11 columns of the file are:

<b>Time</b>	[hour]: time in hours from the first hour of the year of the simulation start.
<b>TairExt</b>	[degree C]: outdoor air temperature.
<b>HHGLO</b>	[W/m <sup>2</sup> ]: incident solar radiation on bridge surface.
<b>TsBridge</b>	[degree C]: surface temperature of the road.
<b>TinBridge</b>	[degree C]: inlet fluid temperature in the bridge flow circuit.
<b>ToutBridge</b>	[degree C]: outlet fluid temperature from the bridge flow circuit.
<b>TmDuct</b>	[degree C]: average temperature of the ground duct store.
<b>TinDuct</b>	[degree C]: inlet fluid temperature in the duct store flow circuit.
<b>ToutDuct</b>	[degree C]: outlet fluid temperature from the duct store flow circuit.
<b>PBridge</b>	[kWh/h]: heat rate transferred by the flow circuit in the bridge.
<b>PDuct</b>	[kWh/h]: heat rate transferred by the flow circuit in the ground duct store.

### A3.6.5 Heat Balance of the System

The quantities contained in the file BRIDGESIM.OUT allows the user to establish an overall heat balance of the system. A diagram of the energy fluxes is shown in Fig. A3.4.

## Global system heat balance

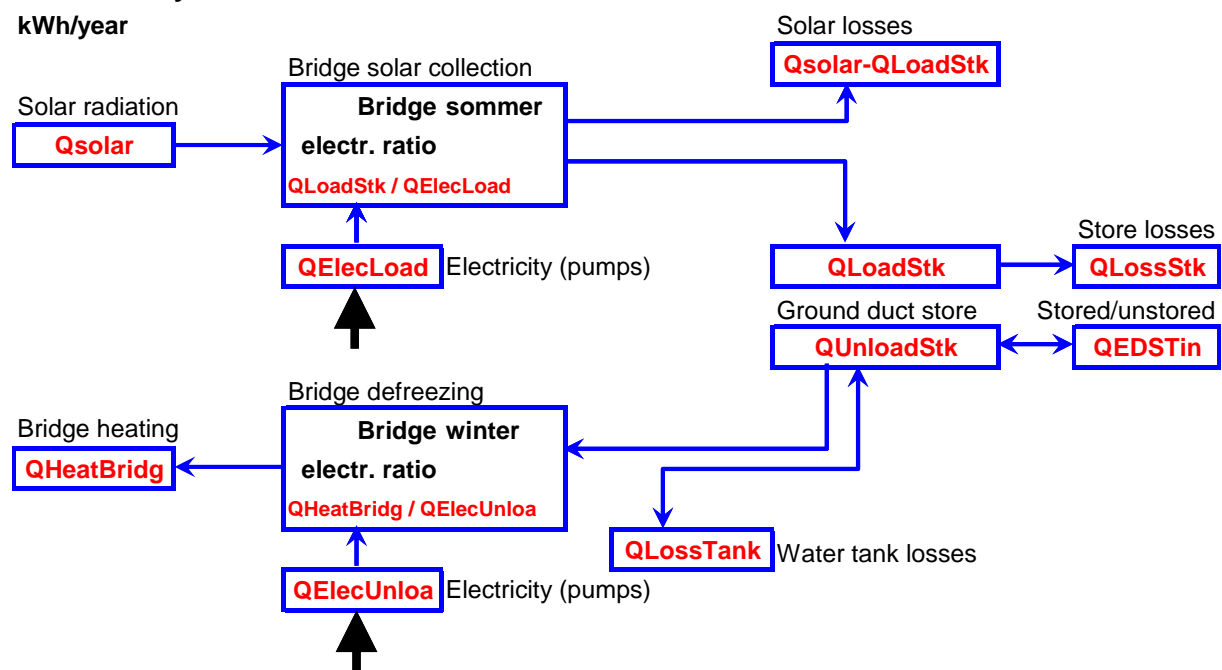


Figure A3.4 System heat balance of the system

The heat quantities are calculated by the first simulation summary:

<b>Qsolar</b>	[kWh]: incident solar radiation on bridge surface.
<b>QLoadStk</b>	[kWh]: stored heat in ground duct store.
<b>QLossStk</b>	[kWh]: duct store heat losses.
<b>QEDSTin</b>	[kWh]: duct store stored energy (variation of its internal energy).
<b>QUnloadStk</b>	[kWh]: recovered heat from ground duct store.
<b>QHeatBridg</b>	[kWh]: heating energy injected into the bridge.
<b>QLossTank</b>	[kWh]: heat losses from the short term water tank.
<b>QElecLoad</b>	[kWh]: circulation pump electric energy for solar gain collection.
<b>QElecUnloa</b>	[kWh]: circulation pump electric energy for bridge heating.

### A3.7 Output results with BRIDGESIM

An excel file has been created with the name BRIDGESIM.XLS in order to produce graphical output results from the output files created by BRIDGESIM. It contains macros that automatically open the output files, copy the content into the BRIDGESIM.XLS file and close them. The global system heat balance is produced together with various design quantities and files. Figure A3.5 shows the various output results that can be produced.

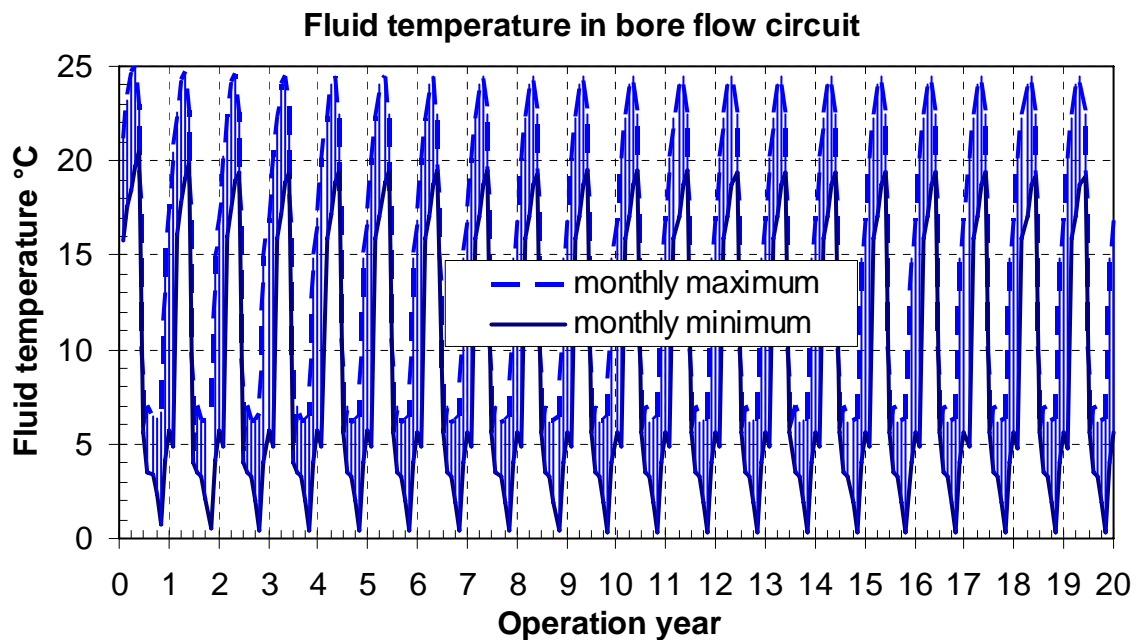
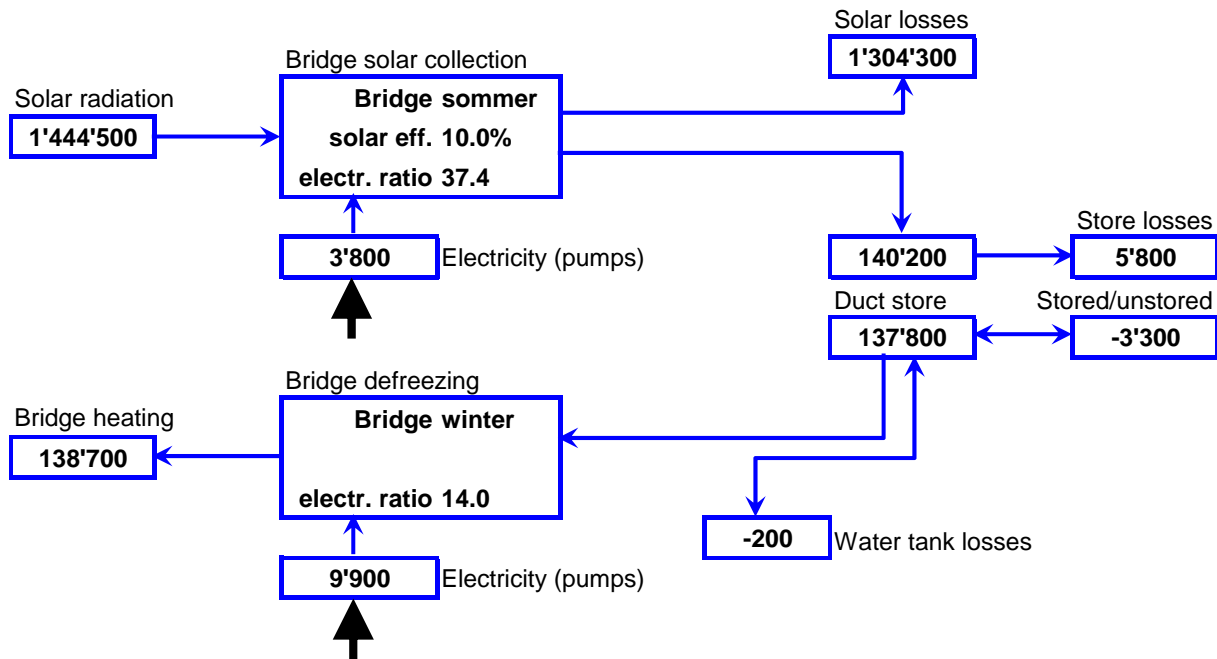


Figure A3.5 Example of output result produced with BRIDGESIM.XLS

# Global system heat balance

kWh/year

mean operation year



Total electric energy for the pumps

13'600	kWh/y
10.1	-

Global system ratio

### Duct store discharge

Heat extraction rate per meter borehole  
Annual extracted energy per meter borehole

Max	Mean	
55	13	W/m
	23	kWh/m/y

Discharge duration  
1'795 hours/y

### Duct store charge

Heat injection rate per meter borehole  
Annual injected energy per meter borehole

Max	Mean	
69	35	W/m
	24	kWh/m/y
	98	%

Charge duration  
682 hours/y

### Duct store efficiency

### Road surface temperature Ts

Number of hours with temperature Ts below 0°C for the last simulated year  
Number of hours with Ts < 0°C and Taria > -4°C for the last simulated year  
Degree-hours NTs for Ts < 0°C and Taria > -4°C for the last simulated year

157	hours/y
27	hours/y
22	Kh/y

Figure A3.5 Example of output result produced with BRIDGESIM.XLS (continued)



### Ground duct store monthly heat balance and temperature levels

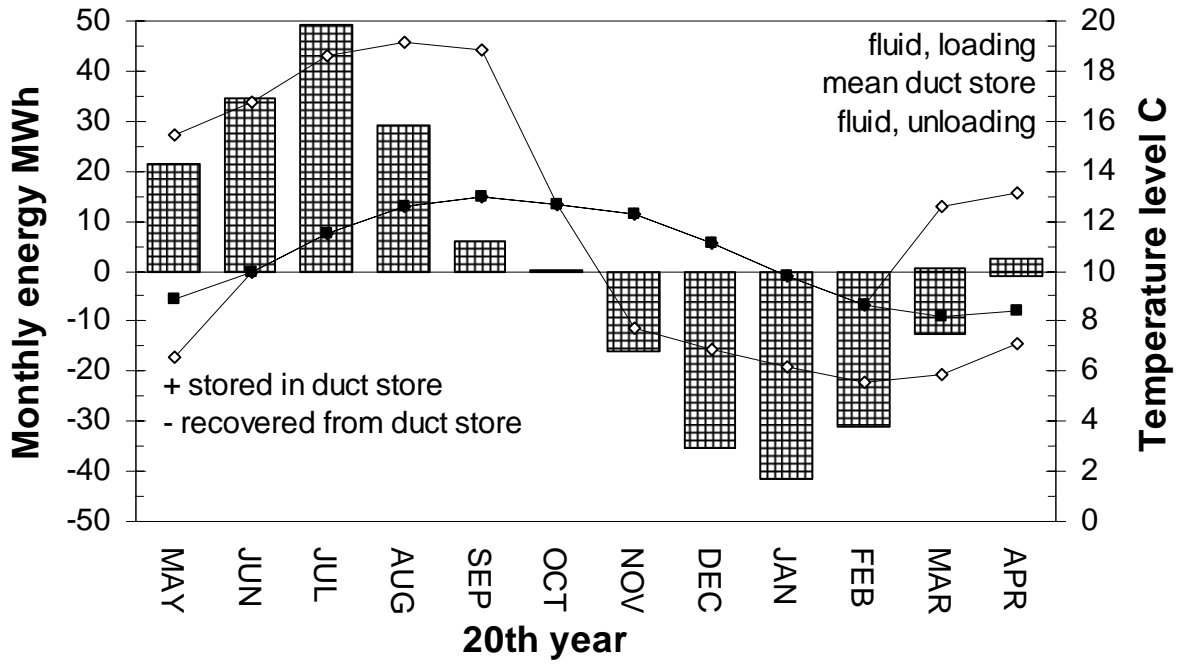


Figure A3.5 Example of output result produced with BRIDGESIM.XLS (continued)

Other macros in BRIDGESIM.XLS allow the user to visualise results of multiple simulations produced with the TRNSED application BRIDGESIM.