TUTORIAL
EXAMPLES FOR EED v4

Jan 9, 2019

The latest version of this document is available at
https://buildingphysics.com/download/exampleseed.pdf

The example files are available at
https://buildingphysics.com/download/EED_4_example_files.zip

Contents

The example files are available at
https://buildingphysics.com/download/EED_4_example_files.zip

General comments on Location and Geology

Ground Surface Temperature and **Geothermal Heat Flux** are dependent on the location of the site. The values given in the two databases are taken from relevant atlases or GIS-data and give a general idea for undisturbed conditions. Hence, they need to be considered in the context of the real environment, e.g. as follows:

- For sites within cities, the value for ground surface temperature should be increased by 1-2 °C, depending on the size and age of the city.
- In places with mountainous geography (like Bergen NO, Stuttgart DE, Trieste IT), values can differ at relative short distance; for sites up on the hills, the value for ground surface temperature should be decreased by up to 1 °C per 100 m altitude above the main city level.

If more detailed local data exist (e.g. mean annual air temperature at the site, which usually equals the ground surface temperature for undisturbed conditions), these data always supersede the values in the databases. This is the case in particular if temperature data from TRT are known; here it is important to take into account that TRT usually gives an average value over depth of the TRT-borehole, while the ground surface temperature from the database is given at the ground surface, as the name implies. So, if such average ground temperature from TRT is used, the value for geothermal heat flux should be set to 0 W/m^2, and the design should be made only for the same depth as the depth of the TRT-borehole.

Concerning the values for **Thermal Conductivity** and **Specific Heat Capacity** of the underground, also these values should be taken with consideration to the context. The databases in most cases give a range and a typical value; the variation within that range is due to differences in mineral composition, weathering, disintegration, compaction etc.), and the soil/rock on a certain site might even be outside the given range. In porous soil/rock, the water content has high impact on both thermal conductivity and specific heat capacity. In this case check for the values of dry/moist/saturated (where available), and interpolate with the moisture content estimated for the underground on site. A value from TRT always should be preferred, however, with the limitation that is can only be accurate for the same depth as the depth of the TRT-borehole.

Example 1: Single Family House (Germany)

Load data as annual total heat/cold and maximum heat pump capacity
Typical example for Western/Central European location

Filename for sample input file: EED_4_SFH-DE.dat

Location: Small village near Gütersloh, Germany

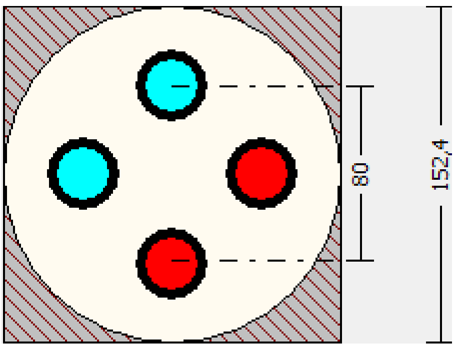
Geology: Intercalation of Cretaceous limestones and marls

Values from database:	Thermal Conductivity	2.20 W/(m*K)
	Volumetric Heat Capacity	2.30 MJ/(m^3*K)
	Ground Surface Temperature	9.20 °C
	Geothermal Heat Flux	0.07 W/m^2

As the site is outside of the city and no further information on the underground is known, the database values are taken without adaptation.

Borehole Data: As a start, 2 BHE 6 m apart and each 100 m deep are considered, with a search for optimum depth later. The following values reflect German practice, with double-U-tube BHE made of PE with SDR11.

Borehole Data:	Type	Double-U
	Configuration	No. 1 (2 BHE)
	Depth	100 m
	Spacing	6 m
	Diameter	152.4 mm (6”)
	Contact resistance	0 (m*K)/W (value for well-grouted borehole)
	Filling thermal conductivity	1.6 W/(m*K) (thermally enhanced grout)
	Vol. flow rate per BHE	2.0 l/s
U-Pipe Data:	Outer diameter	32 mm
	Wall thickness	3 mm
	Thermal conductivity	0.42 W/(m*K)
	Shank spacing	80 mm



Graph of BHE cross-section as prepared by EED

Borehole Thermal Resistance: “Calculate Values” and “Account for Internal Heat Transfer” are ticked.

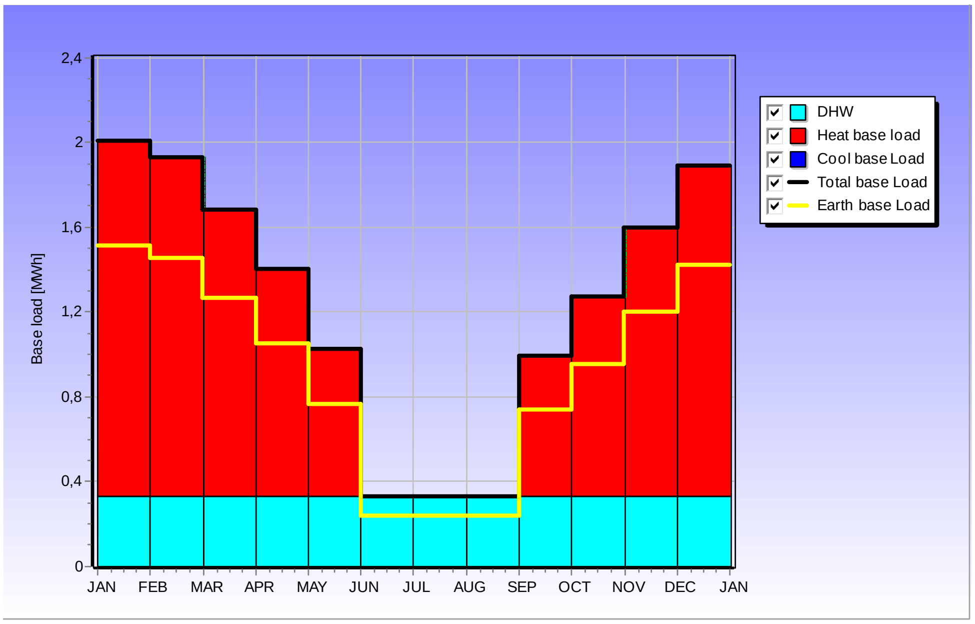
Heat Carrier Fluid: The values for a mixture of 25% monoethylen-glycole in water are selected:

Thermal conductivity	0.48 W/(m*K)
Specific heat capacity	3795 J/(kg*K)
Density	1052 kg/m^3
Viscosity	0.0052 kg/(m*s)
Freezing point	-14 °C

Load Data: The calculated annual heat demand for space heating of the building is 10.8 MWh, and an additional 4.0 MWh annually for domestic hot water (DHW). While the space heating can be done with about 35 °C supply temperature (slab heating), the DHW requires the full 55-60 °C the heat pump can deliver. Hence the seasonal performance factor (SPF) is 4.2 for space heating, but drops down to 3.5 during preparation of DHW. The heat pump foreseen for the building has a maximum heating output of 9.5 kW, achieved during space heating. A small heat pump of 9.5 kW heating output usually has a single-stage compressor, and either operates at (near) maximum capacity or is switched of, resulting in a maximum output of 9.5 kW in each month. Only the daily operation hours vary with seasonal demand. For heat pumps with capacity control, typical values for maximum output would have to be set, based on the heat pump performance characteristics (not done in this example).

Base Load Data: The option “Annual energy and monthly profile” is chosen.

Heat annual	10.8 MWh
Heat SPF	4.2
Cool annual	0 (no cooling)
Cool SPF	with no cooling load, the value in this field is not used
Monthly profile	default values are kept
DHW heat annual	4.0 MWh
DHW SPF	3.5



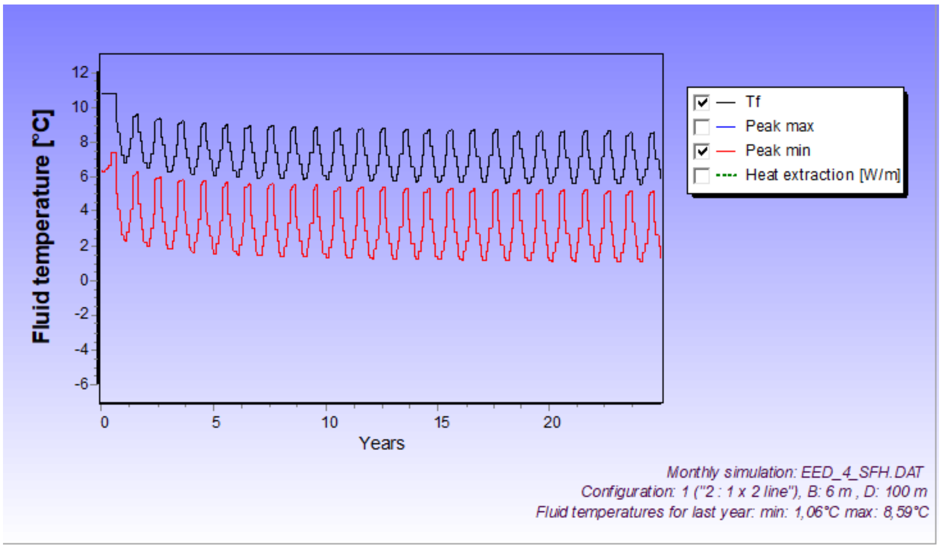
Graph of Base Load data as prepared by EED; the yellow line shows the resulting net heat extraction per month from the ground

Peak Load Data:	Peak Heat Power	9.5 kW
	Peak Heat Duration	1.5-12 hours per day (see file)
	Peak Cool Power	0 kW (no cooling)
	Peak Cool Duration	0 h (no cooling)
	SPF is automatically taken from Base Load Heat / Cold	

Simulation Period: 25 year and month 9 (September, beginning of heating season) are selected.

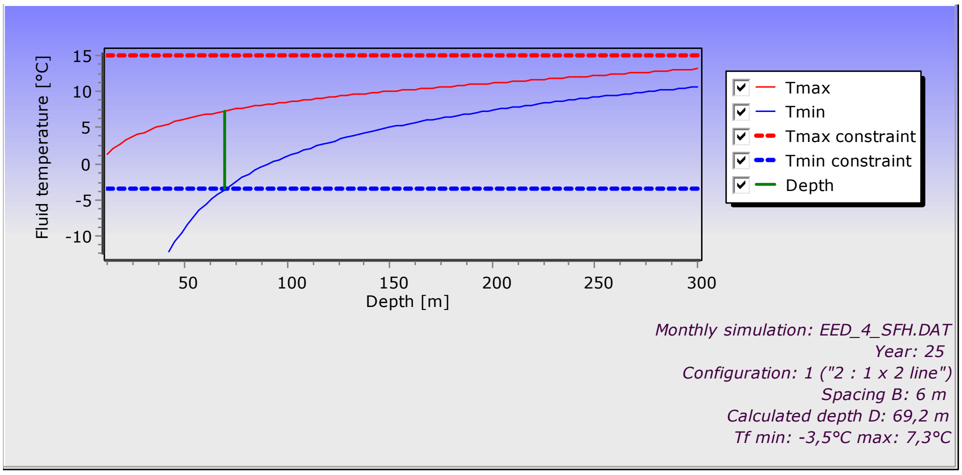
The drop-down menus “Hourly Calculation” and “Irregular Configuration” are not used for this example.

Results: When using “Solve mean fluid temperature”, the temperature development based on the data given is calculated over the given time (25 years). The temperature values are mean temperatures inside the BHE, with the inlet to the BHE lower and outlet from the BHE higher in heating mode. As the graph below shows, the temperature decrease over 25 years levels out, and even at maximum heating conditions the temperatures stay well above 0 °C.

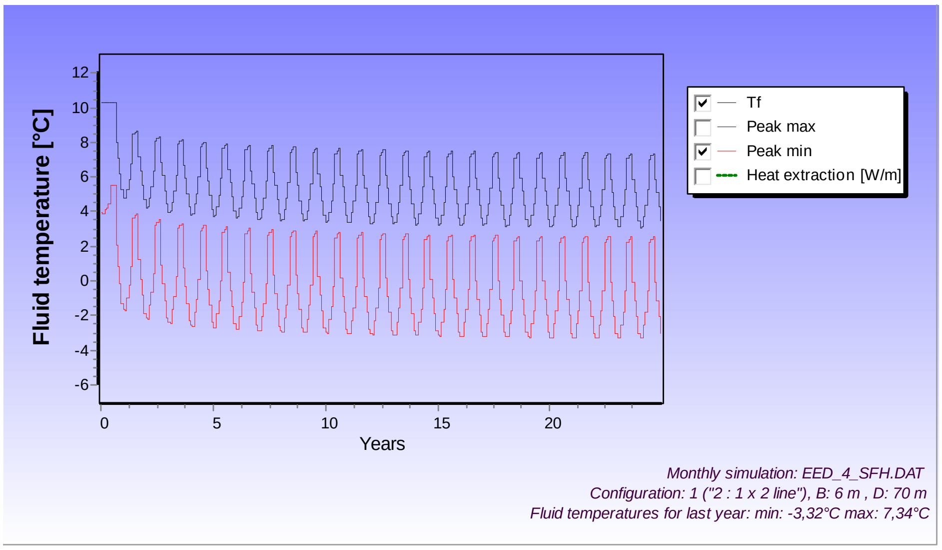


Graph of fluid temperature development for base load (Tf) and maximum heating (Peak min) cases; maximum cooling not shown, as it is identical to base load in a case with no cooling

As a minimum temperature of -5 °C exiting the heat pump (and entering the BHE) is considered acceptable e.g. by VDI 4640-2, the 2 BHE each 100 m deep would be somewhat oversized. The function "Solve required borehole length" allows for adjustment of the BHE length to a given minimum temperature. With a typical temperature spread in the BHE of 3 K between inlet and outlet, a temperature of -5 °C at the inlet would mean -3.5 °C mean temperature inside the BHE (the value calculated by EED). This value of -3.5 °C thus is entered as minimum mean fluid temperature in the "Fluid temperature constraints" drop-down menu under "Solve", and the "Include peak loads" box ticked. The maximum mean fluid temperature is of no importance when no cooling is done, however, the value must be higher than the undisturbed ground temperature. As shown in the graph below, 2 BHE each 70 m deep would be fully adequate for the single-family house in Gütersloh. With this new value as input, the calculation "Solve mean fluid temperature" can be repeated to see the expected development (graph on next page).



Graph of fluid temperature versus depth from "Solve required borehole length" tool



Graph of fluid temperature development for base load (Tf) and maximum heating (Peak min) cases for 2 BHE each 70 m deep

Example 2: Single Family House (Sweden)

Load data as annual total heat/cold and maximum heat pump capacity
Typical example for Nordic location

Filename for sample input file: EED_4_SFH-SE.dat

Location: Rural outskirts of Stockholm area, Sweden

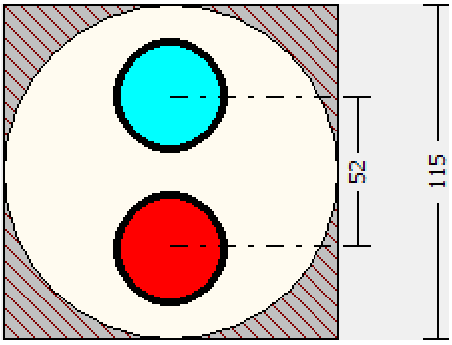
Geology: Granite under few meters of overburden

Values from database:	Thermal Conductivity	3.40 W/(m*K)
	Volumetric Heat Capacity	2.40 MJ/(m^3*K)
	Ground Surface Temperature	6.60 °C
	Geothermal Heat Flux	0.05 W/m^2

As the site is outside of the city and no further information on the underground is known, the database values are taken without adaptation.

Borehole Data: As a start, 1 BHE 150 m deep is considered, with a search for optimum depth later. The following values reflect Swedish practice, with single-U-tube BHE made of PE with SDR17 in a groundwater-filled borehole. Typically, the borehole diameter is 115 mm (4 ½") or 140 mm (5 ½") for deeper boreholes or larger borehole heat exchangers. The flow rate is chosen so that non-laminar flow conditions is attained inside the U-tube during design conditions (minimum mean fluid temperature equal to -2 °C). The Re number, which is indicative of the flow conditions, is then about 2750 as recommended by ASHRAE. The filling thermal conductivity is chosen so as to match field data regarding heat extraction from groundwater-filled boreholes in Sweden. The value depends on borehole water temperature and heat transfer rate due to the influence of natural convection in the groundwater between the U-pipe and the borehole wall. The chosen value of 1,3 W/m,K is therefore slightly higher than the value for stagnant water (0.6 W/m,K).

Borehole Data:	Type	Single-U
	Configuration	No. 0 (1 BHE)
	Depth	150 m
	Spacing	0 m (value not used)
	Diameter	115.0 mm (4 1/2")
	Contact resistance	0 (m*K)/W (value for water-filled borehole)
	Filling thermal conductivity	1.3 W/(m*K) (water)
	Vol. flow rate per BHE	0.55 l/s
U-Pipe Data:	Outer diameter	40 mm
	Wall thickness	2.4 mm
	Thermal conductivity	0.42 W/(m*K)
	Shank spacing	52 mm



Graph of BHE cross-section as prepared by EED

Borehole Thermal Resistance: “Calculate Values” and “Account for Internal Heat Transfer” are ticked.

Heat Carrier Fluid: The values for a mixture of 29% ethanol in water are selected:

Thermal conductivity	0.407 W/(m*K)
Specific heat capacity	4213 J/(kg*K)
Density	969 kg/m^3
Viscosity	0.0070 kg/(m*s)
Freezing point	-18,5 °C

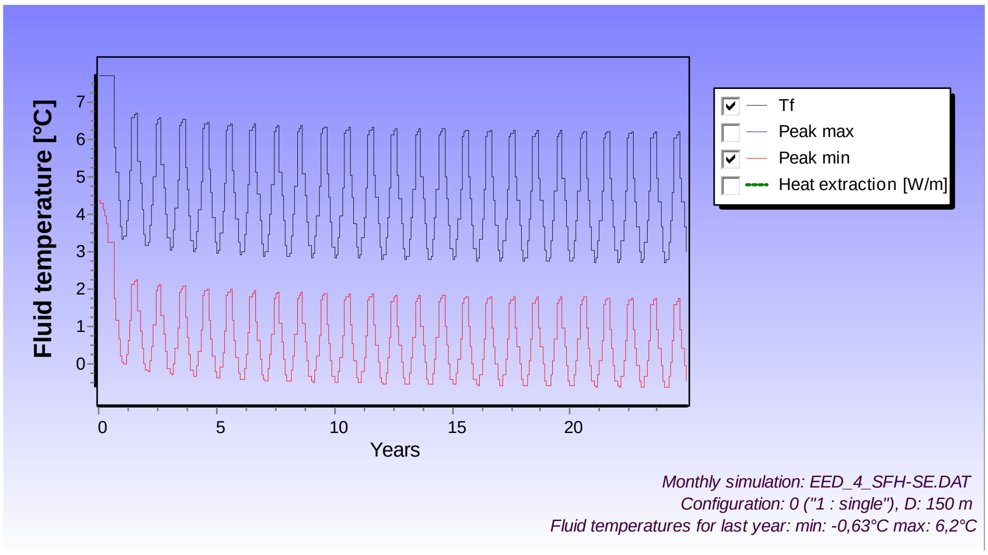
Load Data: As in example 1; the colder climate is deemed to be offset by better insulation, DHW is more dependent on number of residents than on climate (graph see under example 1). For peak load, a slightly smaller heat pump is foreseen considering the high insulation standard, resulting in longer running hours to achieve the same annual heat production. (about 2450 full-load hours per year compared to ca 1550 h/y in example 1). Swedish heat pumps are typically fitted with an electric resistance heater to ensure full capacity at design conditions.

Base Load Data:	The option “Annual energy and monthly profile” is chosen.	
	Heat annual	10.8 MWh
	Heat SPF	4.2
	Cool annual	0 (no cooling)
	Cool SPF	with no cooling load, the value in this field is not used
	Monthly profile	default values are kept
	DHW heat annual	4.0 MWh
	DHW SPF	3.5
Peak Load Data:	Peak Heat Power	6.0 kW
	Peak Heat Duration	3-18 hours per day (see file)
	Peak Cool Power	0 kW (no cooling)
	Peak Cool Duration	0 h (no cooling)
	SPF is automatically taken from Base Load Heat / Cold	

Simulation Period: 25 year and month 9 (September, beginning of heating season) are selected.

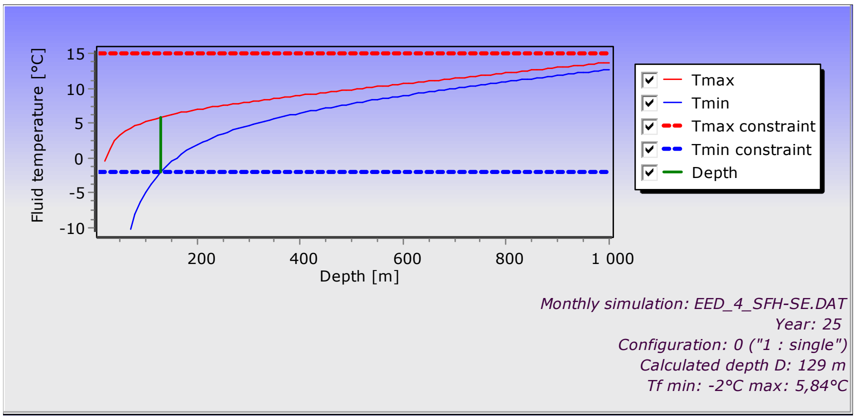
The drop-down menus “Hourly Calculation” and “Irregular Configuration” are not used for this example.

Results: When using “Solve mean fluid temperature”, the temperature development based on the data given is calculated over the given time (25 years). The temperature values are mean temperatures inside the BHE, with the inlet to the BHE lower and outlet from the BHE higher in heating mode. As the graph below shows, the temperature decrease over 25 years levels out, but at maximum heating conditions the temperatures drop down to -0.63 °C.

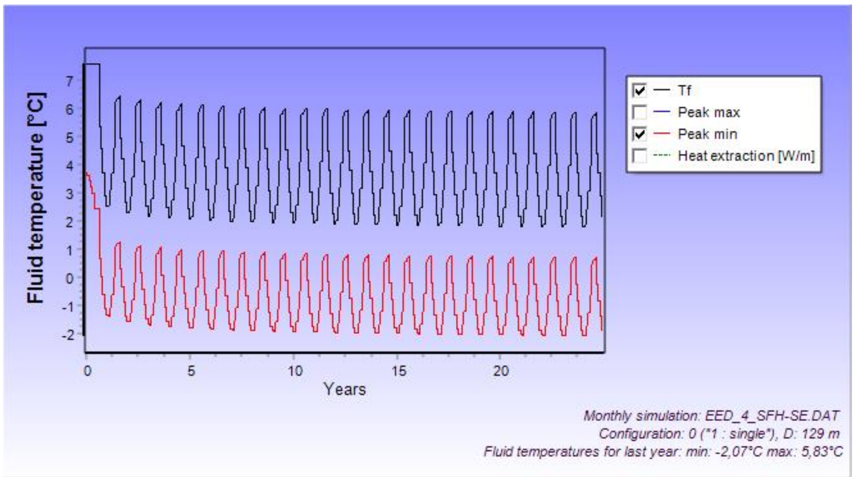


Graph of fluid temperature development for base load (Tf) and maximum heating (Peak min) cases; maximum cooling not shown, as it is identical to base load in a case with no cooling

The design criteria of a minimum mean temperature of -2 °C inside the BHE (typical for -3.5 °C fluid exiting the heat pump / entering the BHE), the BHE can actually be shorter. Hence the value of -2 °C is entered as minimum mean fluid temperature in the “Fluid temperature constraints” drop-down menu under “Solve”, and the “Include peak loads” box ticked. The maximum mean fluid temperature again is of no importance. Using the “Solve required borehole length” tool, 1 BHE of 129 m depth would be required for the single-family house in the outskirts of Stockholm (see graph below). With this new value as input, the calculation “Solve mean fluid temperature” can be repeated to see the expected development (graph on next page).



Graph of fluid temperature versus depth from “Solve required borehole length” tool



Graph of fluid temperature development for base load (Tf) and maximum heating (Peak min) cases for 1 BHE 129 m deep

Example 3: Single Family House (Greece)

Load data as annual total heat/cold and maximum heat pump capacity
Typical example for Southern European location
Filename for sample input file: EED_4_SFH-GR.dat

Location: Village in the region of Thessaloniki, Greece

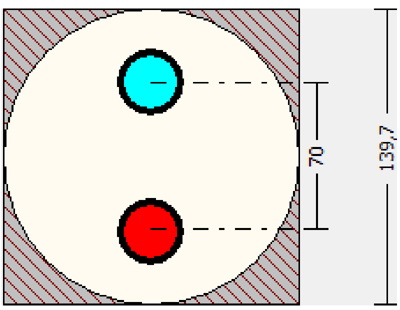
Geology: Massive limestone banks

Values from database:	Thermal Conductivity	2.80 W/(m*K)
	Volumetric Heat Capacity	2.30 MJ/(m^3*K)
	Ground Surface Temperature	16.20 °C
	Geothermal Heat Flux	0.08 W/m^2

As the site is outside of a city and no further information on the underground is known, the database values are taken without adaptation.

Borehole Data: As a start, 2 BHE 6 m apart and each 100 m deep are considered, with a search for optimum depth later. The following values reflect Mediterranean practice, with single-U-tube BHE made of PE with SDR11.

Borehole Data:	Type	Single-U
	Configuration	No. 1 (2 BHE)
	Depth	100 m
	Spacing	6 m
	Diameter	139.7 mm (5½”)
	Contact resistance	0.1 (m*K)/W (value for not fully grouted borehole)
	Filling thermal conductivity	0.8 W/(m*K) (standard bentonite/cement grout)
	Vol. flow rate per BHE	2.0 l/s
U-Pipe Data:	Outer diameter	32 mm
	Wall thickness	3.0 mm
	Thermal conductivity	0.42 W/(m*K)
	Shank spacing	70 mm



Graph of BHE cross-section as prepared by EED

Borehole Thermal Resistance: “Calculate Values” and “Account for Internal Heat Transfer” are ticked.

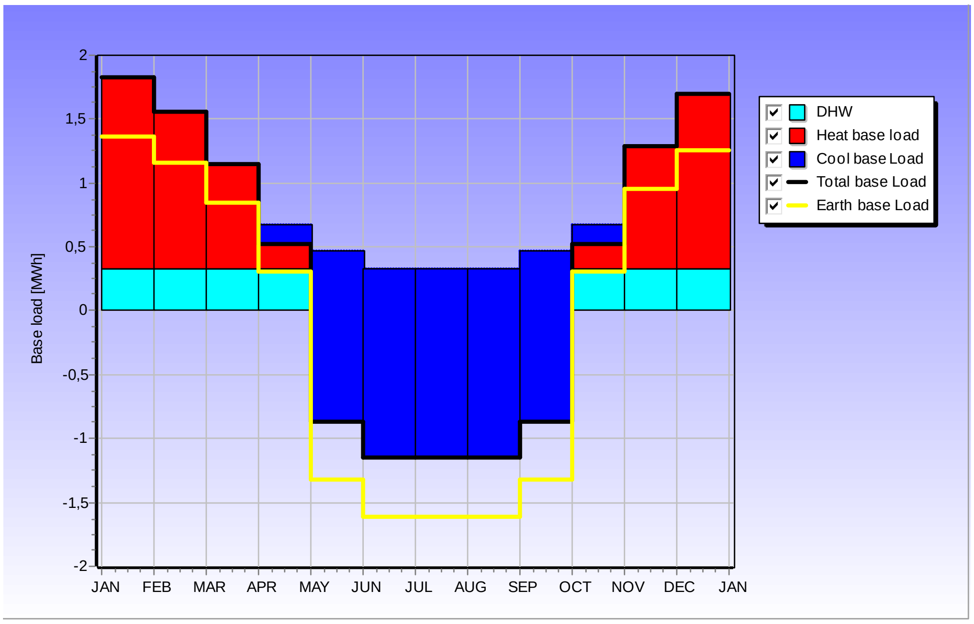
Heat Carrier Fluid: The values for pure water are selected, at 10 °C average temperature:

Thermal conductivity	0.58 W/(m*K)
Specific heat capacity	4192 J/(kg*K)
Density	999.8 kg/m^3
Viscosity	0.0013 kg/(m*s)
Freezing point	0 °C

Load Data: The calculated annual heat demand for space heating of the building is 6.8 MWh, the calculated cooling demand is 7.4 MWh, and an additional 4.0 MWh annually is required for domestic hot water (DHW). Both space heating and cooling are done using fan-coil units; supply temperature in winter up to 40 °C and in summer in the range of 8-16 °C. The DHW requires the full 55-60 °C the heat pump can deliver. Hence the seasonal performance factor (SPF) is 4.0 for space heating and cooling, but drops down to 3.5 during preparation of DHW. The heat pump foreseen for the building has a maximum heating output of 9.0 kW, achieved during space heating. The maximum cooling capacity (evaporator capacity) of this heat pump is 6.8 kW. Further operation characteristics as in example 1.

Base Load Data: The option “Annual energy and monthly profile” is chosen.

Heat annual	6.8 MWh
Heat SPF	4.0
Cool annual	7.4 MWh
Cool SPF	4.0
Monthly profile	values need to be adapted to lower heat demand and cooling (see file)
DHW heat annual	4.0 MWh
DHW SPF	3.5



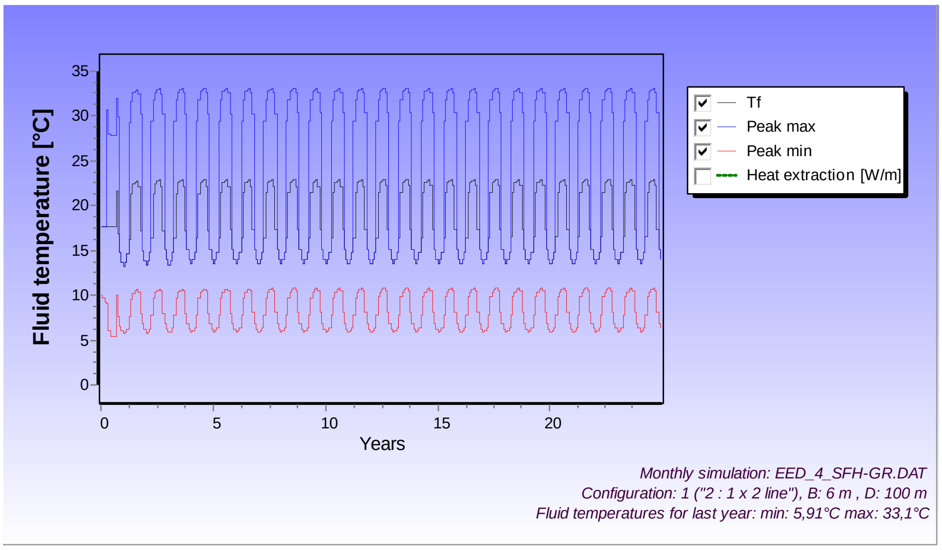
Graph of Base Load data as prepared by EED; the yellow line shows the resulting net heat extraction per month from the ground and heat injection into the ground, respectively

Peak Load Data:	Peak Heat Power	9.0 kW
	Peak Heat Duration	2-8 hours per day (see file)
	Peak Cool Power	6.8 kW (active cooling)
	Peak Cool Duration	4-12 hours per day (see file)
	SPF is automatically taken from Base Load Heat / Cold	

Simulation Period: 25 year and month 9 (September, beginning of heating season) are selected.

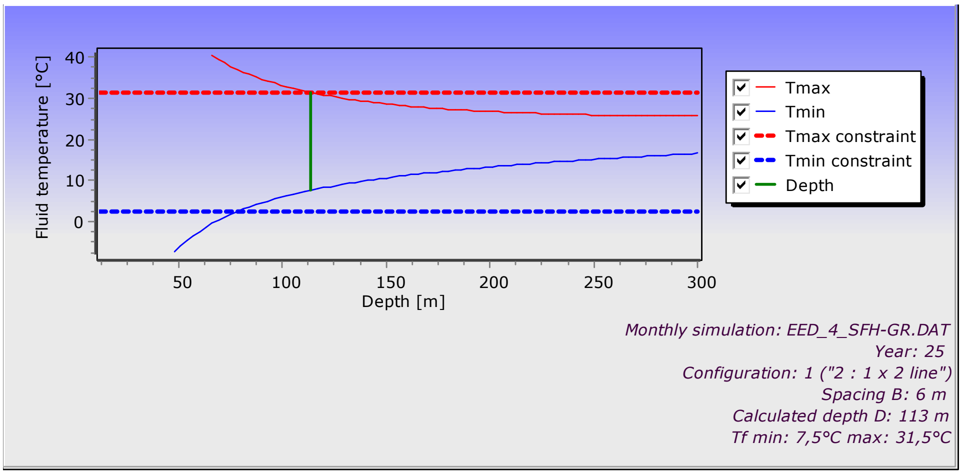
The drop-down menus “Hourly Calculation” and “Irregular Configuration” are not used for this example.

Results: When using “Solve mean fluid temperature”, the temperature development based on the data given is calculated over the given time (25 years). The temperature values are mean temperatures inside the BHE, with the inlet to the BHE lower and outlet from the BHE higher in heating mode (and vice versa in cooling mode). As the graph below shows, the temperature levels over 25 years are quite stable. This shows that heat extraction during heating and heat injection during cooling are balanced over the seasons. The minimum values are well above 0 °C, while the maximum values exceed 30 °C.



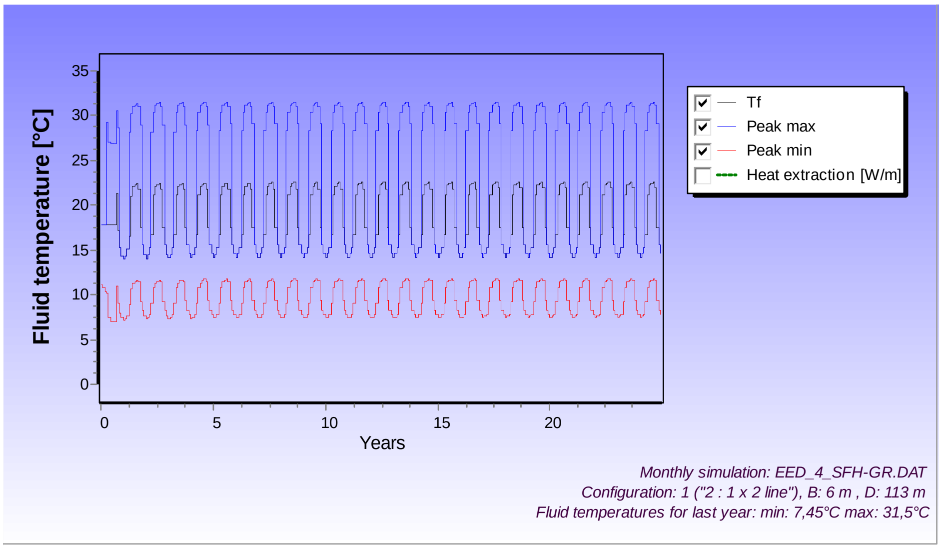
Graph of fluid temperature development for base load (Tf), maximum heating (Peak min) and maximum cooling (Peak max) cases

Maximum temperatures in active cooling mode (i.e. with the heat pump acting as water chiller) are regulated in some countries, e.g. to 25 °C or 30 °C. Technically all temperatures below those achieved by air-cooled condensers provide an efficiency gain. To check what BHE length would be required to keep the temperature entering the heat pump at a maximum of 30 °C in summer, the function "Solve required borehole length" is used. For a temperature spread of 3 K between inlet and outlet, a value of the mean fluid temperature of 31.5 °C would mean 30 °C entering the heat pump in cooling mode. For the minimum temperature, a value of 2.5 °C is entered, to guarantee a temperature at least 1 K above the freezing point of water. As shown in the graph below, 2 BHE each 113 m deep would be required for the single-family house near Thessaloniki. The minimum temperature in this case is no problem, it would rise to 7.5 °C mean fluid temperature and thus far from possible freezing. With the new value for BHE depth as input, the calculation "Solve mean fluid temperature" can be repeated to see the expected development (graph on next page).



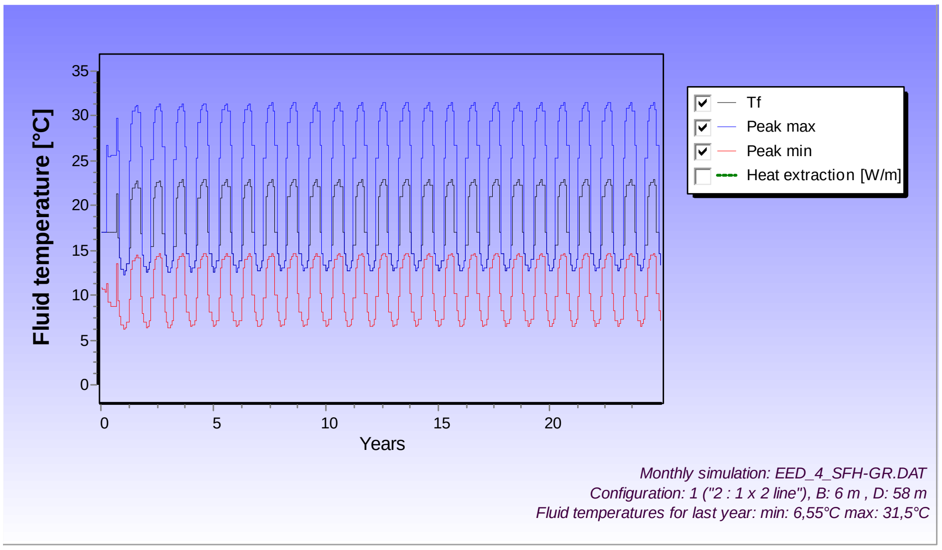
Graph of fluid temperature versus depth from "Solve required borehole length" tool

A decision has to be made if the better efficiency possible with 2 BHE 113 m deep or the lower first cost with 2 BHE 100 m deep are more important; both version and everything in between would basically work.



Graph of fluid temperature development for base load (Tf), maximum heating (Peak min) and maximum cooling (Peak max) cases for 2 BHE each 113 m deep

In a further test, it was checked what the impact of using a double-U-BHE with all the properties as in example 1 would be in the case of example 3. In fact, 2 BHE each 58 m deep would be sufficient under these circumstances, a reduction to about half the BHE length.



A comparison of the German (1) and Swedish (2) example shows 2 BHE each 70 m (total 140 m) for a site with lower thermal conductivity of the ground and better BHE in Germany versus 1 BHE 129 m deep with higher thermal conductivity of the ground and a simpler, cheaper BHE in a groundwater-filled borehole. When comparing both heating-only examples to the cooling-dominated example in Greece (3), a larger total BHE length of 200-226 m is required to meet the substantial cooling load.

Example 4: Small office building (France)

Load data as monthly values for heat/cold and maximum heat pump capacity
Filename for sample input file: EED_4_OFFICE-S.dat

Location: In the city of Lille, France

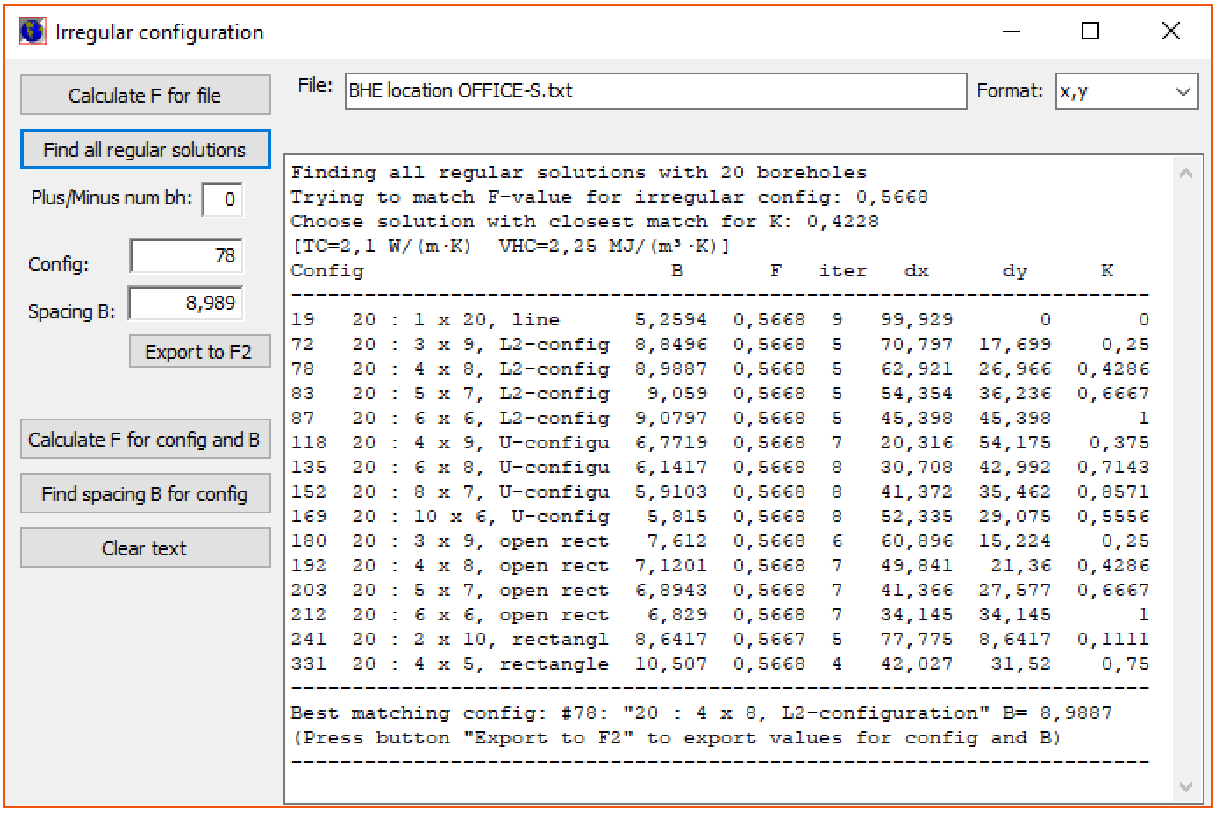
Geology: Because of the size of the project, a test BHE was installed to a depth of 95 m, and a TRT performed. The geology in the test borehole was:

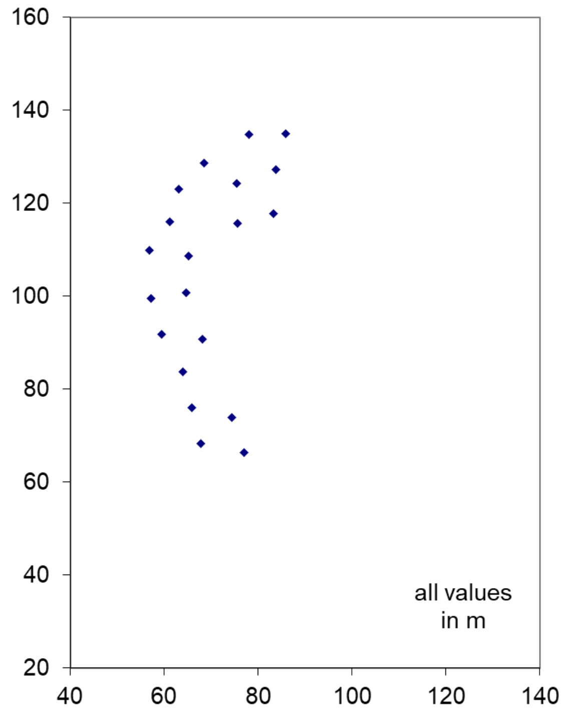
	Silt and sand with clay lenses	0-45 m depth
	Sandstone and siltstone, marl	45-95 m depth
Values from TRT:	Thermal Conductivity	2.10 W/(m*K)
	Volumetric Heat Capacity	2.25 MJ/(m^3*K)
	Ground Surface Temperature (in this case average temperature over BHE length)	12.30 °C
	Geothermal Heat Flux (set to 0, as the geothermal gradient is included in TRT)	0.00 W/m^2

The average temperature over 95 m depth calculated with the values in the database would be 11.5 °C. The higher values is due to the location being inside the city. The thermal conductivity and heat capacity are representing the mean value for the layers perforated. The values are only valid for a BHE 95 m deep; should a change in length be desired, the value can be used for validating the input parameters for a calculation within EED at the 95-m-mark.

Borehole Data: As a start, a field with 20 BHE a minimum 6 m apart is considered, with BHE each 95 m deep. Some site constraints (boundary, planned building, existing trees, subsurface infrastructure, etc.) limit the area available and prohibit certain spots. As a result, a typical regular configuration like 4 x 5 cannot be used. The possible positions for the maximum number of 20 BHE are shown in the graph on next page, and the coordinated given in the list beside it (see also file “BHE location OFFICE-S.txt”).

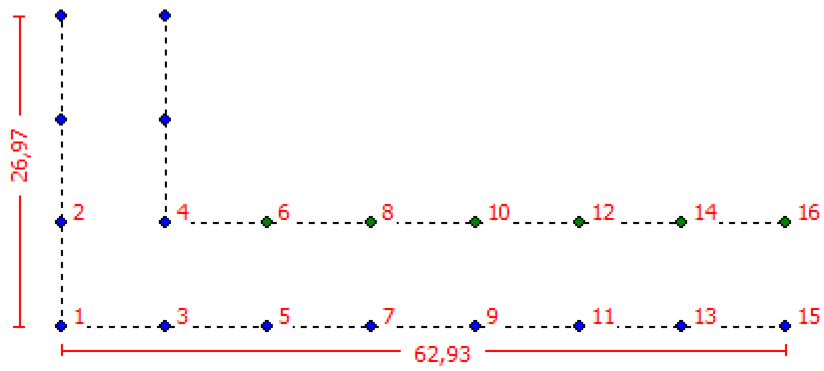
The tool for “irregular configuration” can be used to find the closest regular configuration for which a g-function exists. The name of the txt-file is typed in the respective field in the drop-down menu, if necessary with the whole path. By clicking “find all regular solutions” the g-functions that are closest are displayed (see below), and the best match can be exported into the “Borehole and heat exchanger” (F2) sub-menu. In this example, it is L2-configuration number 78 (20 BHE) with 8.99 m average distance between BHE.


Irregular configuration
Calculate F for file
Find all regular solutions
Plus/Minus num bh: 0
Config: 78
Spacing B: 8,989
Export to F2
Calculate F for config and B
Find spacing B for config
Clear text
File: BHE location OFFICE-S.txt
Format: x,y
Finding all regular solutions with 20 boreholes
Trying to match F-value for irregular config: 0,5668
Choose solution with closest match for K: 0,4228
[TC=2,1 W/(m·K) VHC=2,25 MJ/(m³·K)]
Config B F iter dx dy K
19 20 : 1 x 20, line 5,2594 0,5668 9 99,929 0 0
72 20 : 3 x 9, L2-config 8,8496 0,5668 5 70,797 17,699 0,25
78 20 : 4 x 8, L2-config 8,9887 0,5668 5 62,921 26,966 0,4286
83 20 : 5 x 7, L2-config 9,059 0,5668 5 54,354 36,236 0,6667
87 20 : 6 x 6, L2-config 9,0797 0,5668 5 45,398 45,398 1
118 20 : 4 x 9, U-configu 6,7719 0,5668 7 20,316 54,175 0,375
135 20 : 6 x 8, U-configu 6,1417 0,5668 8 30,708 42,992 0,7143
152 20 : 8 x 7, U-configu 5,9103 0,5668 8 41,372 35,462 0,8571
169 20 : 10 x 6, U-config 5,815 0,5668 8 52,335 29,075 0,5556
180 20 : 3 x 9, open rect 7,612 0,5668 6 60,896 15,224 0,25
192 20 : 4 x 8, open rect 7,1201 0,5668 7 49,841 21,36 0,4286
203 20 : 5 x 7, open rect 6,8943 0,5668 7 41,366 27,577 0,6667
212 20 : 6 x 6, open rect 6,829 0,5668 7 34,145 34,145 1
241 20 : 2 x 10, rectangl 8,6417 0,5667 5 77,775 8,6417 0,1111
331 20 : 4 x 5, rectangle 10,507 0,5668 4 42,027 31,52 0,75
Best matching config: #78: "20 : 4 x 8, L2-configuration" B= 8,9887
(Press button "Export to F2" to export values for config and B)



Graph of BHE locations

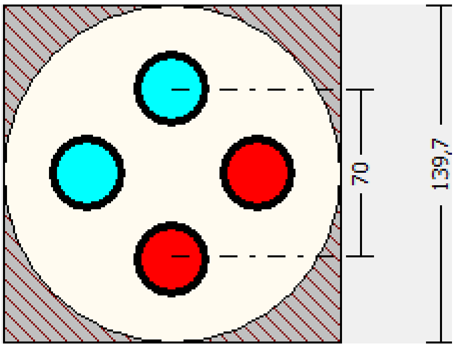
R in m	H in m
77.03	66.39
67.77	68.25
74.32	73.91
65.94	76.06
63.92	83.75
68.10	90.73
64.65	100.76
59.39	91.85
57.20	99.55
56.91	109.89
65.21	108.69
61.27	116.09
63.05	122.99
68.56	128.62
75.46	124.24
75.57	115.74
83.28	117.77
83.74	127.24
77.96	134.82
85.92	135.01



Graph of L2-configuration number 78 as prepared by EED

Borehole Data:	Type	Double-U
	Configuration	No. 78 (20 BHE)
	Depth	95 m
	Spacing	8.99 m
	Diameter	139.7 mm (5½")
	Contact resistance	0 (m*K)/W (value for well grouted borehole)
	Filling thermal conductivity	1.6 W/(m*K) (thermally enhanced grout)
	Vol. flow rate per BHE	2.0 l/s

U-Pipe Data:	Outer diameter	32 mm
	Wall thickness	2.9 mm
	Thermal conductivity	0.42 W/(m*K)
	Shank spacing	70 mm



Graph of BHE cross-section as prepared by EED

Borehole Thermal Resistance: The value obtained from TRT was 0.075 (m*K)/W. This value could be inserted directly by ticking "Use constant values", if exactly the same BHE and grout will be used as in the BHE for TRT. Generally it is recommended to check if the value calculated in EED with the same geometry and materials matches the TRT-value (0.074 (m*K)/W calculated and 0.075 (m*K)/W measured in this example), and then tick "Calculate Values" and "Account for Internal Heat Transfer".

Heat Carrier Fluid: The values for a mixture of 25% monoethylenglycole in water are selected:

Thermal conductivity	0.48 W/(m*K)
Specific heat capacity	3795 J/(kg*K)
Density	1052 kg/m^3
Viscosity	0.0052 kg/(m*s)
Freezing point	-14 °C

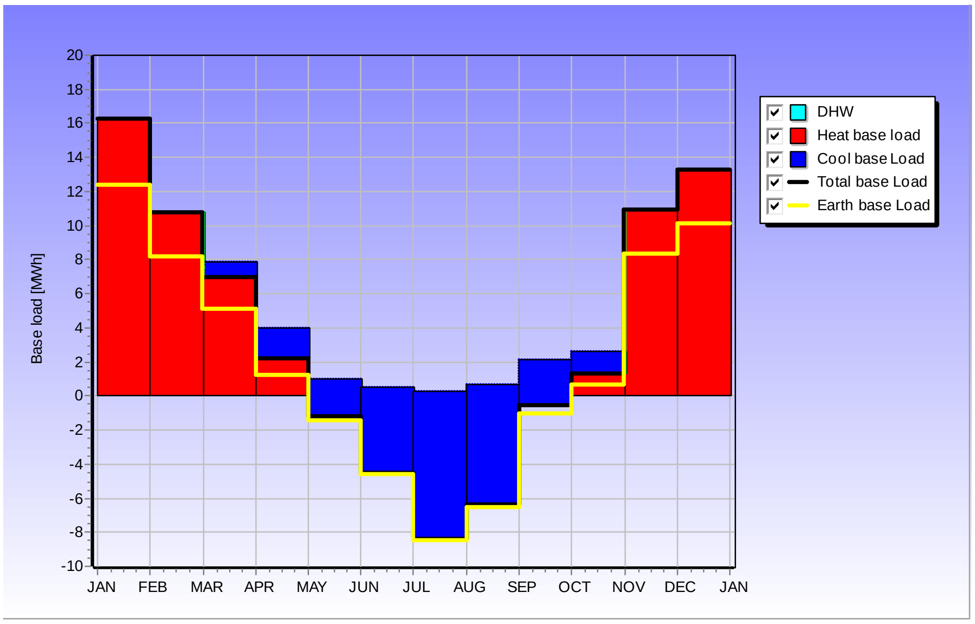
Load Data: A building simulation was done to determine the heating and cooling loads. The total annual heat demand for space heating of the building was calculated to 70.5 MWh, with the monthly values as in the list below. Due to the location in Northern France the cooling demand is much less than the heating demand, calculated to an annual total of 29.6 MWh; the monthly values for cooling are also listed below. As is typical for an office building, DHW is not produced centrally, but prepared by electric boilers in the pantries etc.

In the modern office with slab heating and cooling ceilings, the seasonal performance factor (SPF) is 4.2 for space heating. Cooling shall be provided as direct cooling (i.e. without the heat pump operating as chiller) via the cooling ceilings. Possible maximum supply temperature in direct cooling mode is dependent on the building system and the climate and has to be specified by the HVAC planners. With cooling ceilings, a temperature of 18 °C entering temperature into the ceiling pipes is a typical value. In most cases, the fluid from the ground circuit is not used directly in the cooling ceilings, but a heat exchanger is placed in between to separate the circuits (e.g. to avoid antifreeze in the building circuit). This means a temperature loss of about 2 K in most cases, resulting in a maximum supply temperature from the ground to the heat exchanger of 16 °C.

	Heating	Cooling
	kWh/month	kWh/month
Jan	16295	0
Feb	10748	0
Mar	7910	915
Apr	3974	1754
May	1032	2220
Jun	551	5020
Jul	303	8695
Aug	684	7033
Sep	2121	2662
Oct	2610	1282
Nov	10956	0
Dec	13317	0
yearly sum	70501	29581

Table of monthly heating and cooling loads as given by building simulation

Base Load Data:	The option “Monthly energy values” is chosen.	
	Heat annual / Cool annual	0.0 MWh (values not used)
	Heat SPF	4.2
	Cool SPF	Box “Direct” ticked
	Monthly values	as to table above (need to be converted to MWh!)
	DHW heat annual	0.0 MWh (no DHW)
	DHW SPF	with no DHW load, the value in this field is not used



Graph of Base Load data as prepared by EED; the yellow line shows the resulting net heat extraction per month from the ground and heat injection into the ground, respectively

Peak Load Data: The maximum heating capacity required is slightly above 50 kW. For efficient operation in part-load conditions, 2 heat pumps with 2 compressors each are planned. This allows for a total of five steps: 15.0 kW (1 heat 1 compressor), 26.0 kW (1 heat pump 2 compressors), 30 kW (2 heat pumps 1 compressor each), 41 kW (1 heat pump 1 compressor and 1 heat pump 2 compressors) and 52 kW (2 heat pumps 2 compressors each). Hence the Peak Heat Power is 52 kW only in winter, and a lower stage in the rest of the year (see input file). In direct cooling mode, no compressor is operating, so the maximum achievable value (based on fluid circulation rate) is considered for all months with cooling.

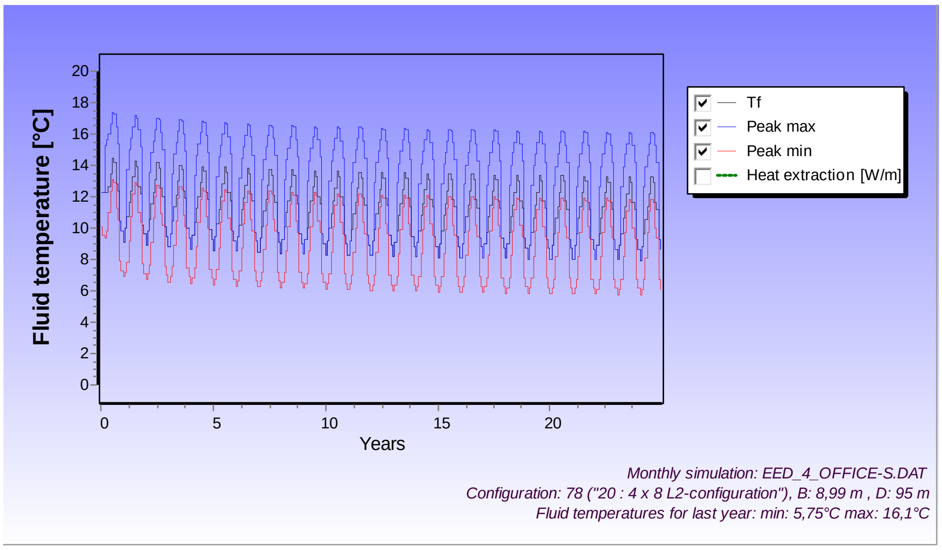
Peak Heat Power	15.0-52.0 kW (heat pump stages)
Peak Heat Duration	2-12 hours per day (see file)
Peak Cool Power	42.0 kW (direct cooling)
Peak Cool Duration	0-10 hours per day (see file)

SPF is automatically taken from Base Load Heat / Cold

Simulation Period: 25 year and month 5 (the office shall be used from May on) are selected.

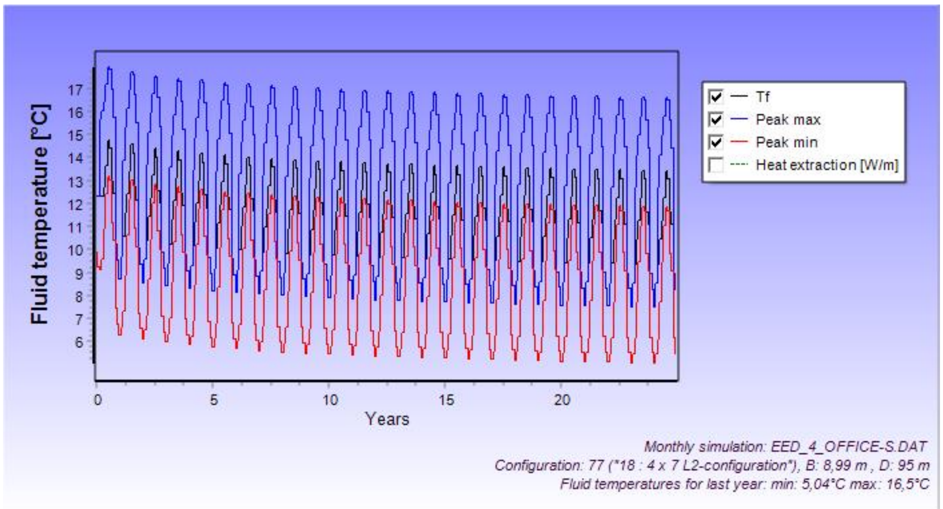
The drop-down menus “Hourly Calculation” is not used for this example.

Results: When using “Solve mean fluid temperature”, the temperature development based on the data given is calculated over the given time (25 years). The temperature values are mean temperatures inside the BHE, with the inlet to the BHE lower and outlet from the BHE higher in heating mode (and vice versa in cooling mode). As the graph below shows, the temperatures level out over 25 years. The minimum values are well above 0 °C, and the maximum values in the first year around 17 °C, decreasing to ca. 16 °C after 25 years.

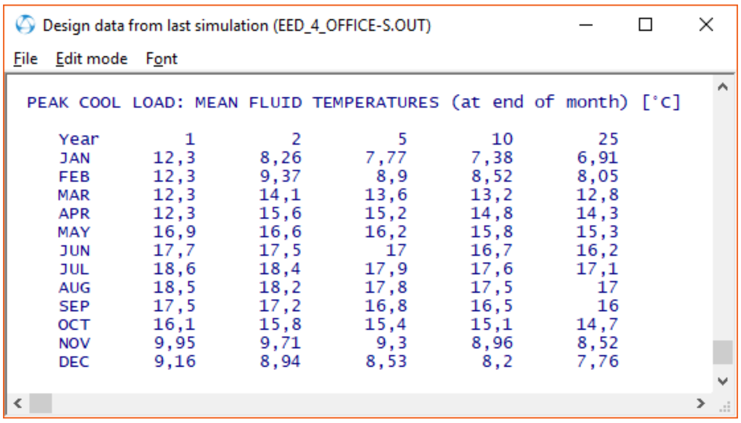


Graph of fluid temperature development for base load (Tf), maximum heating (Peak min) and maximum cooling (Peak max) cases

The maximum temperatures are slightly lower than the limit given by the cooling ceilings; for a temperature spread of 3 K between inlet and outlet of the BHEs, a value of 16 °C entering the heat exchanger in cooling mode would allow for a mean fluid temperature of 17.5 °C in the BHE circuit. Hence an optimization is done by reducing the number of BHE (the length of 95 m is kept fixed in this case). The configuration with 18 BHE (number 77) is inserted and the calculation repeated.



Graph of fluid temperature development for base load (Tf), maximum heating (Peak min) and maximum cooling (Peak max) cases for 18 BHE each 95 m deep (g-function 77)



Design data from last simulation (EED_4_OFFICE-S.OUT)

File Edit mode Font

PEAK COOL LOAD: MEAN FLUID TEMPERATURES (at end of month) [°C]

Year	1	2	5	10	25
JAN	12,3	8,26	7,77	7,38	6,91
FEB	12,3	9,37	8,9	8,52	8,05
MAR	12,3	14,1	13,6	13,2	12,8
APR	12,3	15,6	15,2	14,8	14,3
MAY	16,9	16,6	16,2	15,8	15,3
JUN	17,7	17,5	17	16,7	16,2
JUL	18,6	18,4	17,9	17,6	17,1
AUG	18,5	18,2	17,8	17,5	17
SEP	17,5	17,2	16,8	16,5	16
OCT	16,1	15,8	15,4	15,1	14,7
NOV	9,95	9,71	9,3	8,96	8,52
DEC	9,16	8,94	8,53	8,2	7,76

Peak cool results as generated by EED (out-file) for 18 BHE each 95 m deep (g-function 77)

The results in the graph and table above show that in the first years the value of mean fluid temperature during peak cooling will be higher than 17.5 °C, up to 18.6 °C, while from ca. 10 years on the limit of 17.5 °C will not be exceeded. The reason is the gradual decrease of underground temperature due to the higher heat extraction in heating mode than heat injection during cooling. For a design decision, several options exist now, depending on the priorities of the building owner:

- Lowest-cost option: 18 BHE each 95 m deep, with accepting that the full cooling demand might not be covered during the first years and room temperatures might slightly exceed the desired value for short periods (if necessary, some mobile air conditioners could be used temporary).
- Balanced option: 19 BHE each 95 m deep, reducing the risk of not meeting the peak cooling demand temporarily; this option is also less dependent on the long-term ground temperature decrease.
- Safest option: 20 BHE each 95 m deep, allowing for a safety margin in the direct cooling mode, and also for sustainable operation in case the annual heating load in practice would be lower than calculated (the two other options rely on the long-term decrease of underground temperature).

The heating mode is somewhat oversized in this example, as design has to respect the cooling limits. Hence heating has no impact on the choice of options. With the mean fluid temperatures above 4.5 °C in all options it might even be considered go without the anti-freeze in the heat carrier fluid (in this case a sensor for entering water temperature to the heat pump is recommended, to enable emergency stop of the heat pump if temperatures fall below a threshold given by the manufacturer). Using water only as heat carrier fluid could also allow to link the BHE-circuit and building cooling circuit without a heat ex-changer for separation, with the result of a possible cooling supply temperature 2 K higher. Again, the number of BHE might be reduced for such scenario (and as the temperatures in heating mode would decrease when doing so, antifreeze might have to be added again…). With EED, the optimization by testing of different scenarios is easy and fast; however, this would go beyond the scope of this example.

Example 5: Large office building (Germany, hourly values)

Load data as hourly values for heat/cold
Filename for sample input file: EED_4_OFFICE-L.dat

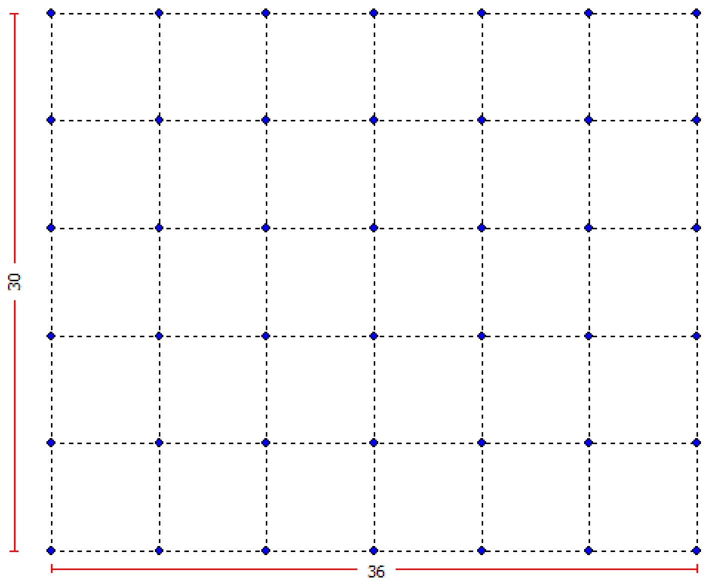
Location: In the city of Wetzlar, Germany

Geology: The underground is dominated by Paleozoic sedimentary rocks (sandstone, some hard limestone, greywacke). Because of the size of the project, a test BHE was installed to a depth of 120 m, and a TRT performed. The geology in the test borehole was:

	Quarternary sand/silt	0-5 m depth
	Greywacke, weathered	5-15 m depth
	Greywacke, solid	15-120 m depth
Values from TRT:	Thermal Conductivity	2.90 W/(m*K)
	Volumetric Heat Capacity	2.20 MJ/(m^3*K)
	Ground Surface Temperature (in this case average temperature over BHE length)	11.20 °C
	Geothermal Heat Flux (set to 0, as the geothermal gradient is included in TRT)	0.00 W/m^2

The values taken from TRT are only valid for BHEs 120 m deep; should a change in length be desired, the value can be used for validating the input parameters for a calculation within EED at the 120-m-mark.

Borehole Data: As a start, a field with 42 BHE a minimum 6 m apart is considered, with BHE each 120 m deep. In a rectangular pattern of 6 x 7 BHE, this would require an area of about 35 x 40 m, including some room for working outside the outer BHE (see graph below). The parking lot and front lawn for the building provides ample space for locating these BHE, and would allow for even more. Thus, the regular rectangular configuration 424 (42 BHE) can be used.

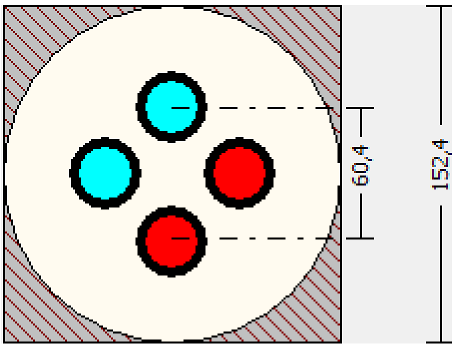


Graph of rectangular configuration number 424 as prepared by EED

Borehole Data:	Type	Double-U
	Configuration	No. 424 (42 BHE)
	Depth	120 m
	Spacing	6.0 m
	Diameter	152.4 mm (6”)
	Contact resistance	0 (m*K)/W (value for well grouted borehole)
	Filling thermal conductivity	1.6 W/(m*K) (thermally enhanced grout)
	Vol. flow rate for all BHE	20.0 l/s

(a flow rate of at least 20 l/s is required to keep the temperature difference of the fluid entering and leaving the heat pump below 3 K at 220 kW in heating mode)

U-Pipe Data:	Outer diameter	32 mm
	Wall thickness	3.0 mm
	Thermal conductivity	0.42 W/(m*K)
	Shank spacing	60.4 mm



Graph of BHE cross-section as prepared by EED

Borehole Thermal Resistance: According to the regulations in force on the level of the respective German state (Hessen), the distance from BHE pipes to borehole wall must be at least 30 mm. This requires a borehole diameter of at least 150 mm for a double-U-BHE with pipes of 32 mm diameter. In this example, a 6” drill bit was is used, equivalent to 152.4 mm diameter. The shank spacing thus can only be 60.4 mm (see graph). This results in a value for the Borehole Thermal Resistance of R_b = 0.103 (m*K)/W.

For comparison, the resistance could be reduced to a value of R_b = 0.081 (m*K)/W with the technically adequate shank spacing of 80 mm. However, the shank spacing as resulting from the regulation must be used, of course.

Heat Carrier Fluid: As temperatures below 0 °C in any part of the system cannot be excluded, a mixture of 25% monoethylenglycole in water is selected, with the following values:

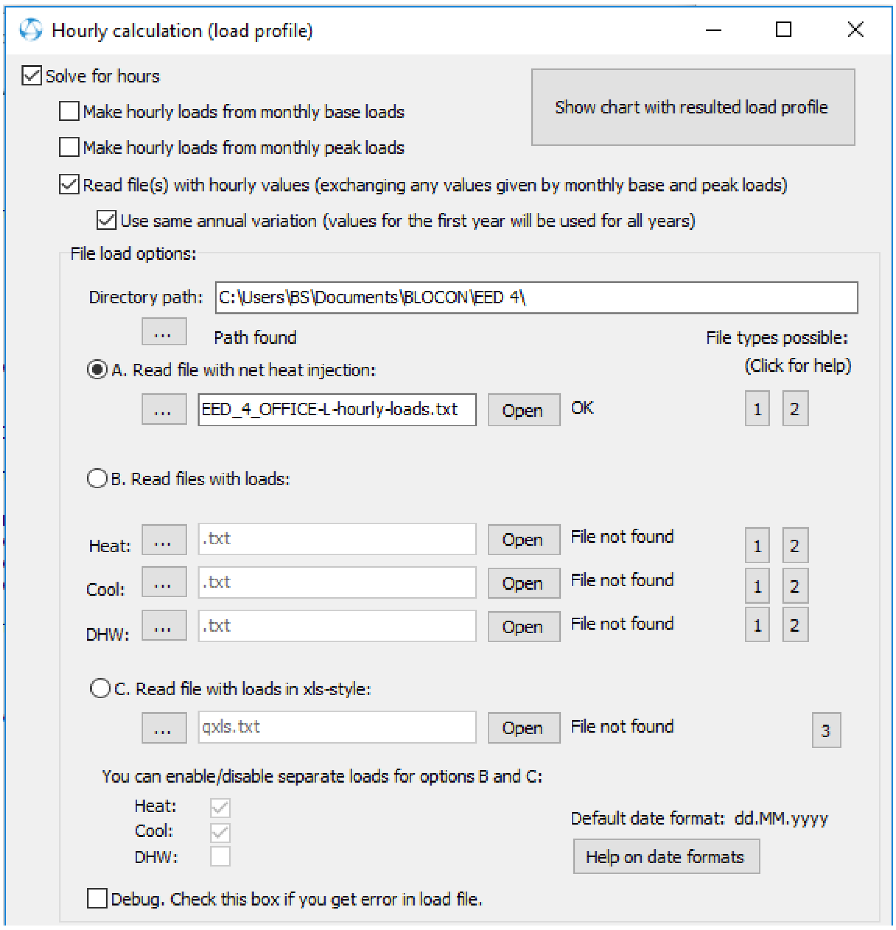
Thermal conductivity	0.48 W/(m*K)
Specific heat capacity	3795 J/(kg*K)
Density	1052 kg/m^3
Viscosity	0.0052 kg/(m*s)

Freezing point -14 °C

Load Data: Hourly Calculation is used in this project (see below). When using hourly calculation and input from files with hourly data, the menus for “Base Load” and “Peak Load” are not used; any values written therein are superseded by the values from the input data file.

Simulation Period: 25 year and month 1 (the hourly data file has values from 1st January on) are selected. To show all results, year 0 is selected for display.

Hourly Calculation: As an hourly load data file exists for the building (see below), the option for “Hourly Calculation (load profile)” is chosen, with the respective drop-down menu (also opening through key F8).



Drop-down menu “Hourly Calculation (load profile)”
[Ps. You need to give your own directory path]

Data can be either given as

(A) Single file with net heat injection (and extraction as negative values, respectively)
(B) Separate load files for heat, cold and DHW
(C) Single file with several columns, xls-style

The file type (1 or 2) determines the way data are represented in the file, either as a continuous series of values for each hour (1), or as a series of heat values and the duration for which each value is achieved (2). Option 1 is very well suited for use of hourly data files provided by building simulation programs. For further detail, please refer to the help buttons in the menu.

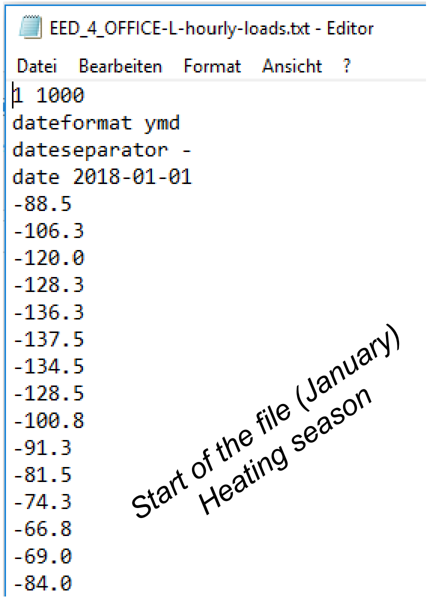
A detailed building simulation (e.g. by TRNSYS or a similar tool) was done to determine the heating and cooling loads. This simulation resulted in a file with hourly values for heating and cooling demand, based on a multi-year-average climate data file for the site. Heat pump efficiency for each hour was also part of the simulation and allowed for determining the actual heat extraction from the ground and heat injection into the ground for each hour of the average year. The following table shows the monthly sums of these hourly values.

	Heat from ground	Heat into ground
	kWh/month	kWh/month
Jan	67‘201	0
Feb	52‘925	0
Mar	28‘101	3
Apr	4‘457	1‘159
May	420	29‘478
Jun	0	51‘404
Jul	0	64‘449
Aug	0	66‘696
Sep	182	20‘555
Oct	1‘645	1‘677
Nov	19‘999	4
Dec	66‘084	0
yearly sum	241‘012	235‘424

Table of monthly heat from and to the ground (for heating and cooling, respectively), as summarized from hourly values provided by building simulation

The total annual heat extraction from the ground (for heating) of about 241 MWh/a is in the same range as the total annual heat injection into the ground (from cooling) of ca 235 MWh/a, making for a rather balanced system on the ground side. The maximum hourly heat extraction in winter is 218.8 kW, the maximum heat injection in summer 270.8 kW.

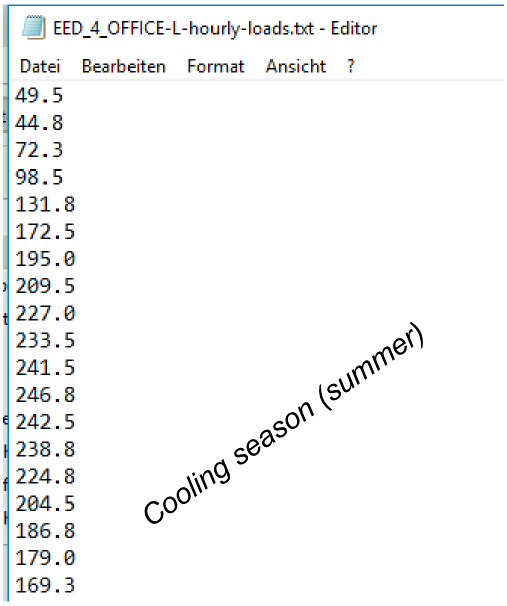
The hourly load data file for option A, net heat injection/extraction, file type 1, is provided as file EED_4_OFFICE-L-hourly-loads.txt. The file content looks as is shown below:



EED_4_OFFICE-L-hourly-loads.txt - Editor

Datei Bearbeiten Format Ansicht ?

```
1 1000
dateformat ymd
dateseparator -
date 2018-01-01
-88.5
-106.3
-120.0
-128.3
-136.3
-137.5
-134.5
-128.5
-100.8
-91.3
-81.5
-74.3
-66.8
-69.0
-84.0
```

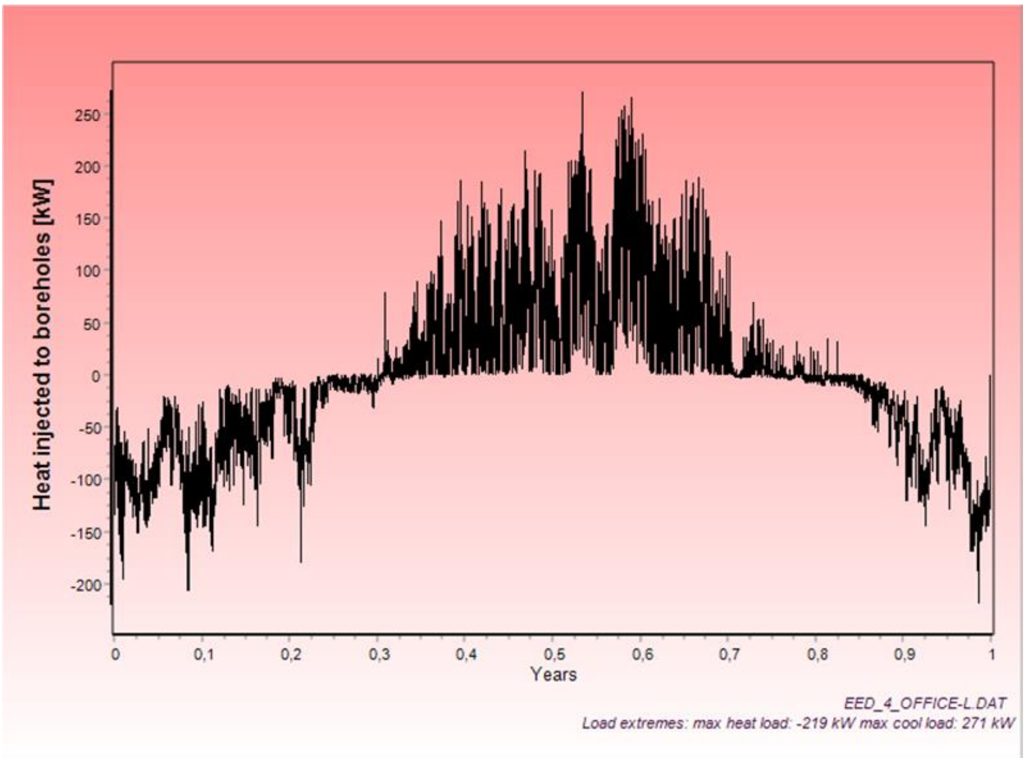
EED_4_OFFICE-L-hourly-loads.txt - Editor

Datei Bearbeiten Format Ansicht ?

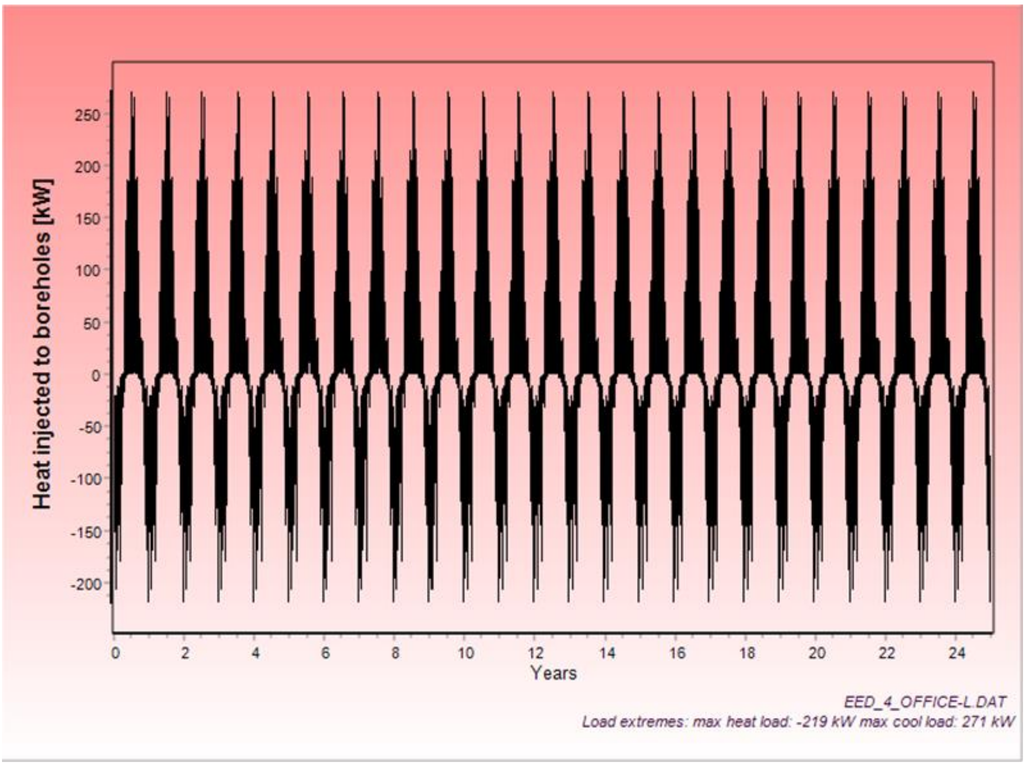
```
49.5
44.8
72.3
98.5
131.8
172.5
195.0
209.5
227.0
233.5
241.5
246.8
242.5
238.8
224.8
204.5
186.8
179.0
169.3
```


Example of hourly data file, start (left) and somewhere in the middle (right); the header determines the format for values and date, followed by starting date and then hourly values

The file contains data for one year, and the load curve resulting from this file is shown below. For the calculation over a given number of years, the values for the first (standard) year can be repeated annually as often as required (see further below).



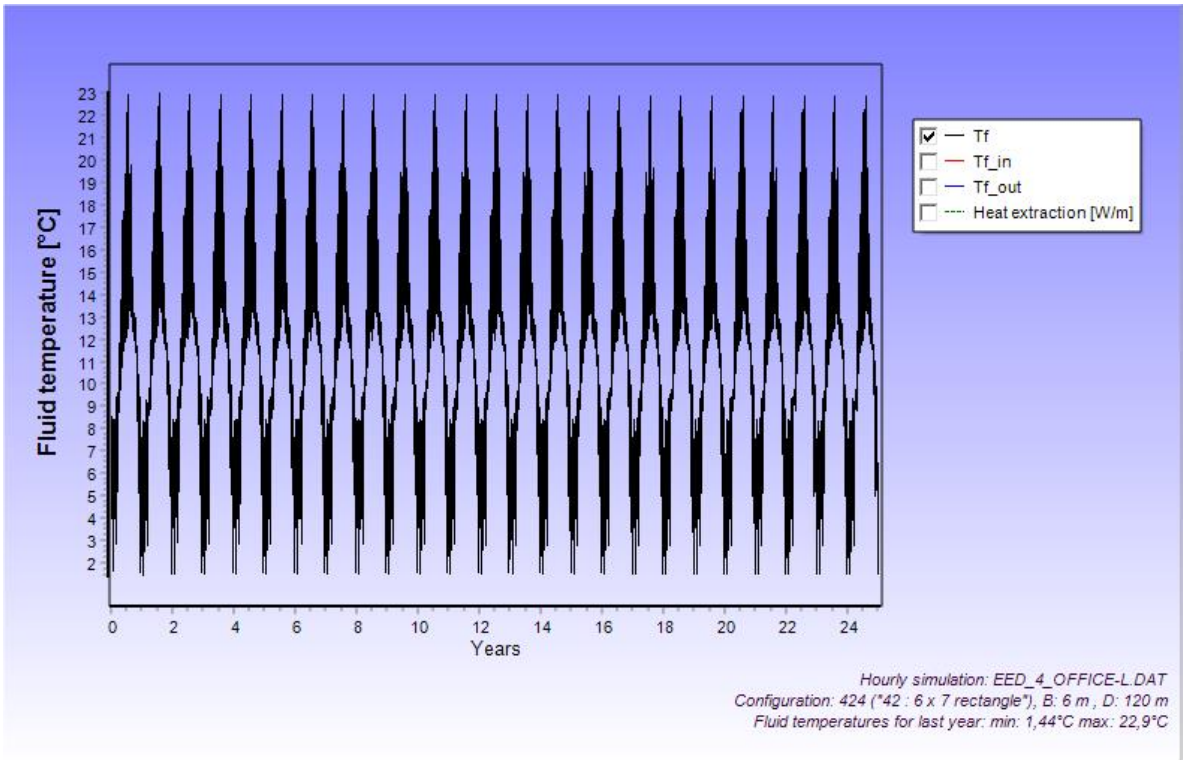
Graph of hourly load data as prepared by EED, for one year; values below 0 indicate heat extraction from the ground (heating for the building), and values above 0 denote heat injection into the ground (cooling of the building)



Graph of hourly load data as prepared by EED, repetition of first year data for 25 years

As an alternative to repeating the first year, a longer file with data for more than a year can be used, allowing for different load curves for each year. The option with repetition of the first year is best suited for planning, while the option with different values for consecutive years can be used e.g. for calculation of temperature behavior in a monitoring exercise (using measured data).

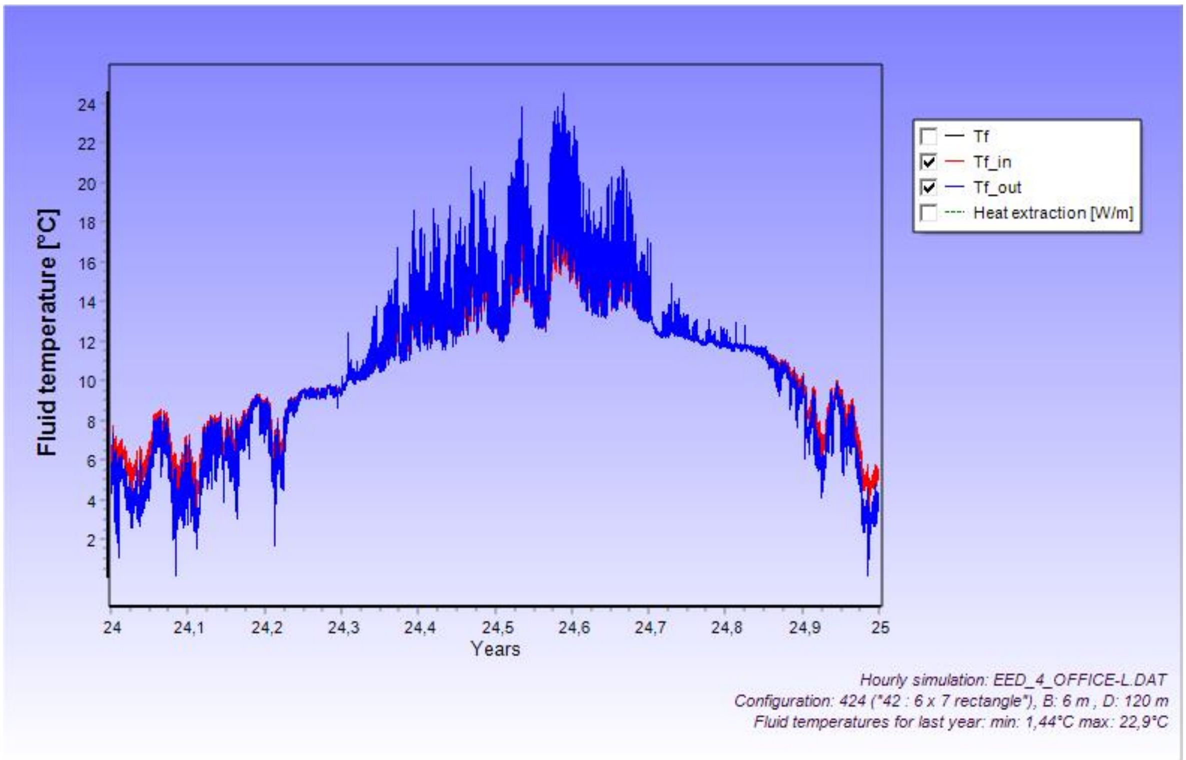
Results: When using “Solve mean fluid temperature”, the temperature development based on the data given in the drop-down menus and the input file is calculated over the given time (25 years). The temperature values are mean temperatures inside the BHE, with the inlet to the BHE lower and outlet from the BHE higher in heating mode (and vice versa in cooling mode). As the graph below shows, the temperature level is rather stable out over 25 years, a result of the well-balanced heat extraction/injection. The minimum values are well above 0 °C, and the maximum values do not exceed 23 C in all years.



Graph of fluid temperature development (Tf) for 25 years

It is possible to extract the values shown in the graphs by using the “Edit chart” sub-menu found in the “Options” tab above the graph. In the tab “Export” within the “Edit chart” sub-menu, the desired data can be selected as well as the format to be exported to. Clicking “Save” within that window will prompt for a file name and export the data to the specified file. Export to a *.txt-file works well, however, depending on the operating system, export to *.xlsx-files is not always successful.

For hourly calculation, EED 4 contains a module to calculate temperatures for fluid entering the heat pump or building system (Entering Water Temperature EWT) and for fluid exiting the heat pump or building system (Leaving Water Temperature LWT). When displaying this in a graph over 25 years, not much can be seen; however, looking at just one year allows to distinguish the two lines and see the temperature spread.



Graph of fluid temperature development (Tf_in for EWT and Tf_out for LWT) for year 25

Example 6: Single Family House (Sweden, hourly values)

Load data as ten-year hourly values

With this example, the use of hourly data in a small project and the difference between load data based on normalised long-term weather data (e.g. 30-year-averages) and loads resulting from real weather development are demonstrated.

Filename for sample input files: EED_4_SFH_SVEBY.dat and EED_4_SFH-SMHI.dat

Location: Rural outskirts of Stockholm area, Sweden

Geology: Granite under few meters of overburden (clay)

Values from database:	Thermal Conductivity	3.50 W/(m*K)
	Volumetric Heat Capacity	2.20 MJ/(m^3*K)
	Ground Surface Temperature (in this case average temperature over BHE length)	8.4 °C
	Geothermal Heat Flux	0.0 W/m^2

The site is North of the city and granite is assumed to have average thermal properties for this region. The initial borehole temperature is based thermal response tests in the vicinity.

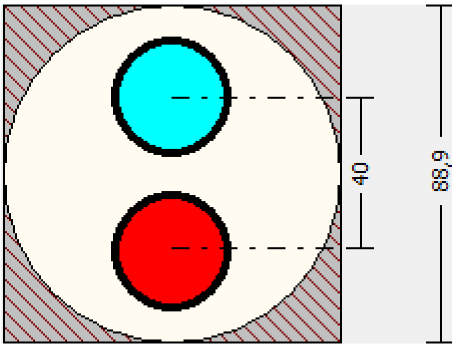
The energy load is a single-family house with heated area of about 100 m² occupied by two adults. The outer walls were further insulated in connection with installation of the ground-source heat pump. The dimensioning heating capacity was estimated to 6,0 kW (100 m² x 60 W/m²). Peak load capacity is available through direct electric heaters installed in the heat cabinet.

The system performance was measured from March 2004 to September 2006. The actual electric consumption was found to be considerably smaller than the design value with a seasonal performance factor of 3.4 for the heat pump. The heat pump coefficient of performance decreases somewhat during periods of low outdoor temperatures or production of domestic water. The peak electric heaters have rarely been used because the installations have turned out be slightly oversized. The balance temperature, above which no space heating is required, was estimated to 13,7 °C.

Borehole Data: The active depth of the borehole is 96.85 m. A single-U-tube BHE made of PE with SDR17 is inserted in the groundwater-filled borehole. A relatively small borehole diameter of 88,9 mm (3 ½”) is used. The standard circulation pump in the heat pump gives a rate of 0.4 liter/second. Non-laminar flow conditions is attained inside the U-tube during design conditions (minimum mean fluid temperature equal to -2 °C) with a . Re number of about 2500. The filling thermal conductivity is chosen so as to match field data regarding heat extraction from groundwater-filled boreholes in Sweden. The value depends on borehole water temperature and heat transfer rate due to the influence of natural convection in the groundwater between the U-pipe and the borehole wall. The chosen value of 1,3 W/m,K is therefore slightly higher than the value for stagnant water (0.6 W/m,K).

Borehole Data:	Type	Single-U
	Configuration	No. 0 (1 BHE)
	Depth	100 m
	Groundwater level	3.15 below ground surface

	Active borehole depth	96.85 m
	Spacing	0 m (value not used)
	Diameter	88.9 mm (3 1/2”)
	Contact resistance	0 (m*K)/W (value for water-filled borehole)
	Filling thermal conductivity	1.3 W/(m*K) (water)
	Vol. flow rate per BHE	0.40 l/s
U-Pipe Data:	Outer diameter	32 mm
	Wall thickness	2.0 mm
	Thermal conductivity	0.42 W/(m*K)
	Shank spacing	40 mm



Graph of BHE cross-section as prepared by EED

Borehole Thermal Resistance: “Calculate Values” and “Account for Internal Heat Transfer” are ticked.

Heat Carrier Fluid: The values for a mixture of 29% ethanol in water are selected:

Thermal conductivity	0.407 W/(m*K)
Specific heat capacity	4213 J/(kg*K)
Density	969 kg/m^3
Viscosity	0.0070 kg/(m*s)
Freezing point	-18.5 °C

Load Data: Hourly Calculation is used in this project (see below). When using hourly calculation and input from files with hourly data, the menus for “Base Load” and “Peak Load” are not used; any values written therein are superseded by the values from the input data file.

Simulation Period: 10 year and month 1 (the hourly data file has values from 1st January on) are selected. To show all results, year 0 is selected for display.

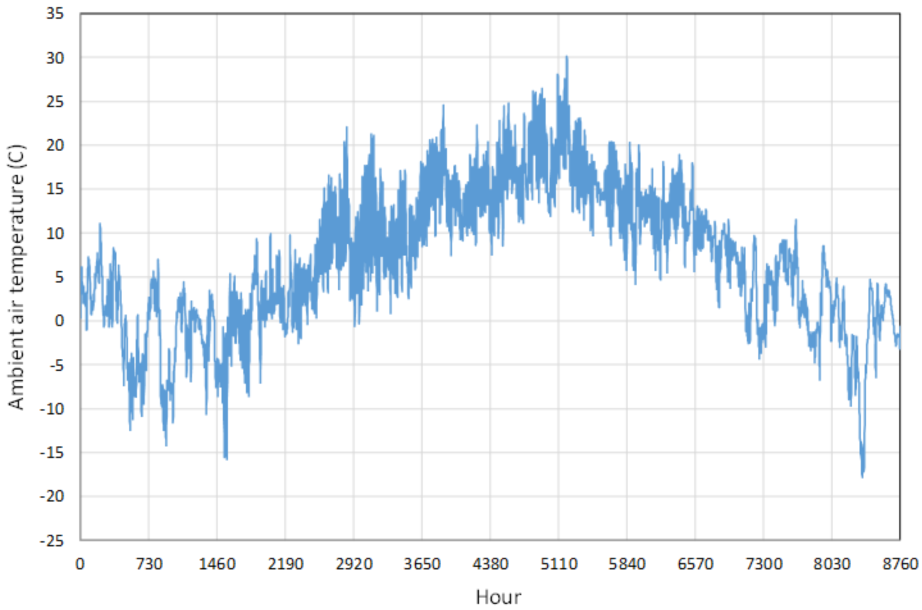
Hourly Calculation: As an hourly load data file exists for the building (see below), the option for “Hourly Calculation (load profile)” is chosen, with the respective drop-down menu (also opening through key F8). See Example 5 for further explanations on how to use the hourly data option.

The load data in this case are generated separately (not inside EED), and are based on actual energy load characteristics and heat pump performance in combination with weather data. As the current version of EED uses a fixed SPF to calculate the ground loads, the actual heat pump performance is used to calculate the ground load for space heating and domestic hot water, and the resulting ground-side loads (at the heat pump evaporator) are obtained. Hourly values for outdoor temperature are used as input for this estimation of heat loads, and two different sets of climate data are used to generate the heat load in this example:

- Measured hourly values for one "normal" year composed of a blend of average months. The "blend" is based on hourly data supplied from SMHI for Stockholm from the period 1981-2010. Such "normalised climate" files are freely available for a large number of locations in Sweden and a part of Swedish design procedure called Sveby (www.sveby.org). [1]
- Measured hourly values from the Swedish Meteorological & Hydrological Institute (SMHI) for Stockholm during the period 2006-2015.

Results for normal year hourly data (Sveby) based on the period 1981-2010:

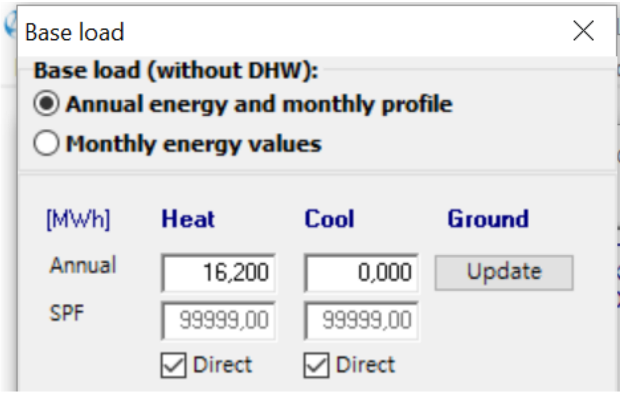
Filename for sample input file: EED_4_SFH_SVEBY.dat
Filenames for sample data files: EED_4_SFH_SVEBY_space.txt
EED_4_SFH_SVEBY_dhw.txt



Graph of "normal month" ambient air temperature variation in Stockholm during the period 1981-2010 (www.sveby.org).

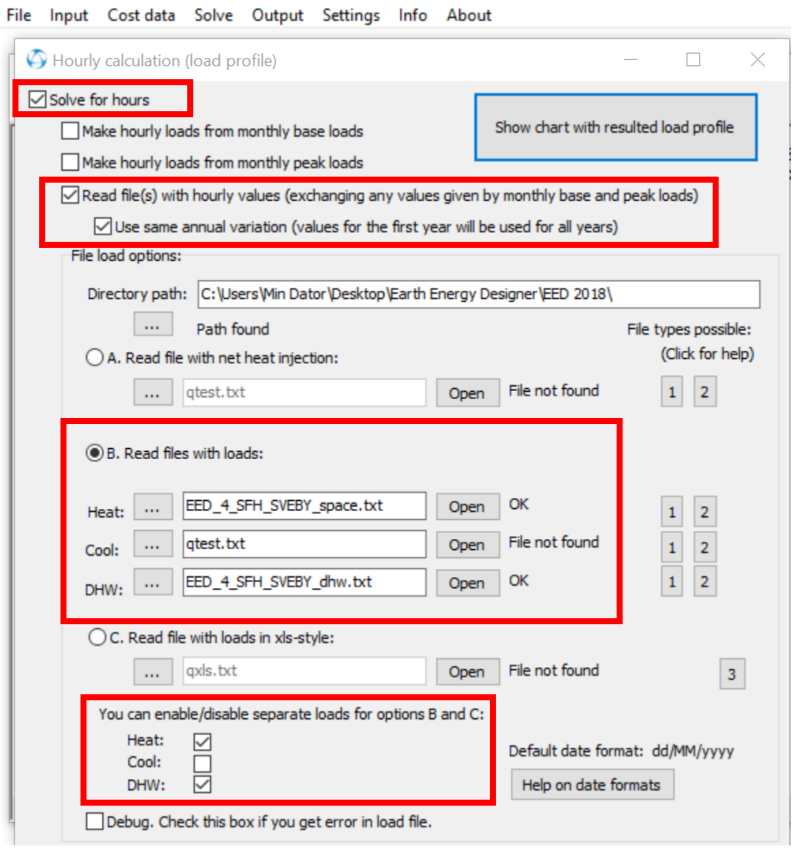
The climate data is used to generate one file for the ground load due to space heating and one file for the ground load due to domestic hot water production. In order to use ground loads the boxes "Direct" is clicked in the "Base Load" submenu. No other values in the "Base Load" and "Peak Load" submenus will be used when hourly loads have been chosen.

[1] The meteorological services in most European countries offer such files. For all of Europe, suitable climate data are available through Meteonorm: https://meteonorm.com/



Click the boxes “Direct” if data for ground loads are given.

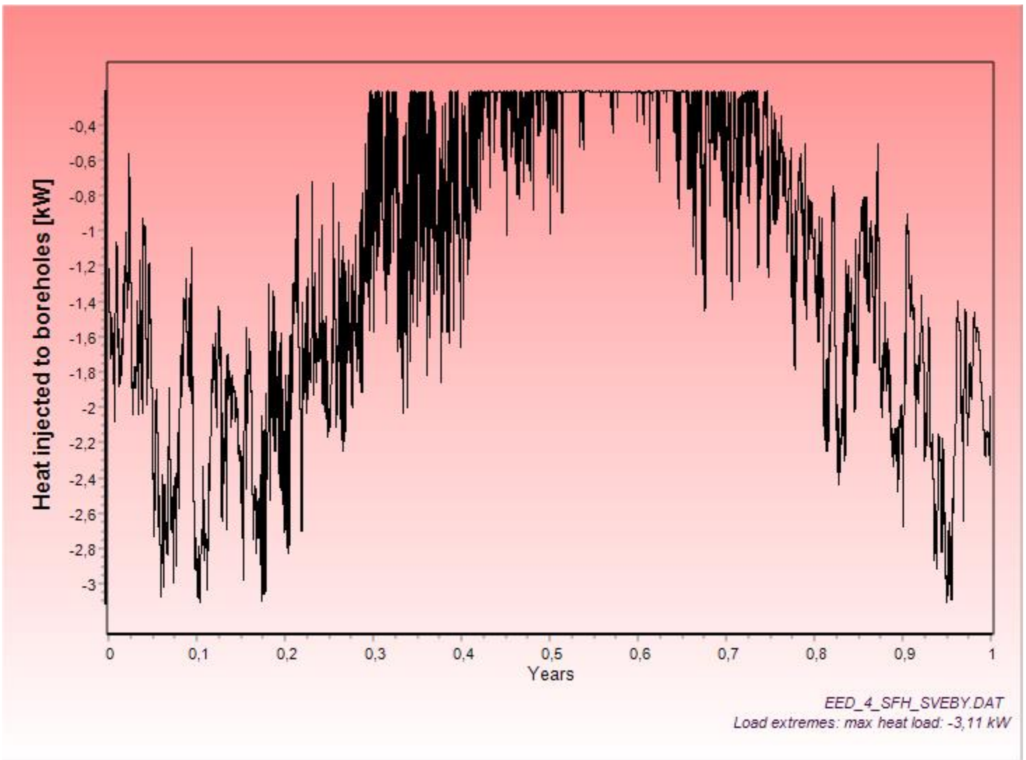
The option for “Hourly Calculation (load profile)” is chosen, with the respective drop-down menu (also opening through key F8). Option B with separate load files for heat and DHW is used. See screen sample below with relevant items highlighted.



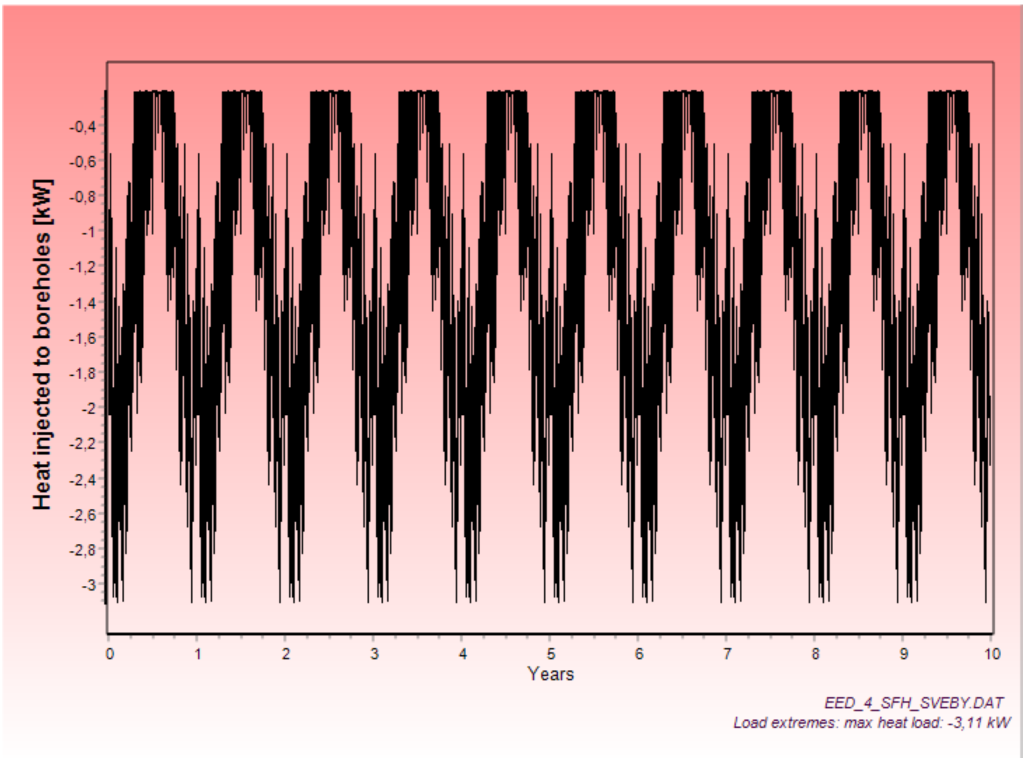
Click the relevant boxes for hourly calculation with annual repetition of data. Give file names for heat and DHW loads.

[Ps. You need to give your own directory path]

The files contain data for one year, and the load curve resulting from this file is shown below. For the calculation over a given number of years, the values for the first (standard) year can be repeated annually as often as required (see further below). The annual ground heat load is 8572 kWh for space heating and 2694 kWh for domestic hot water production.

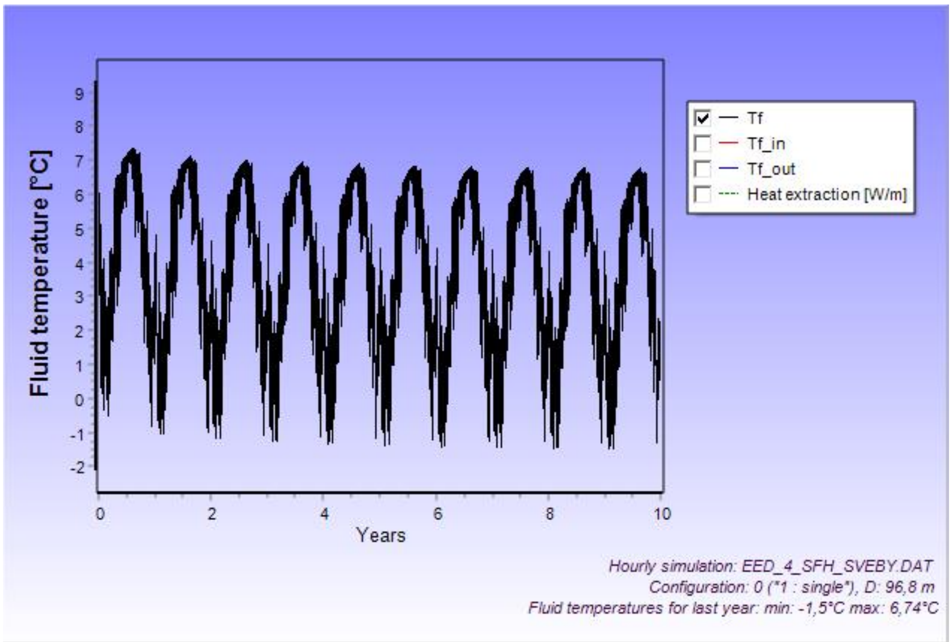


Graph of hourly load data as prepared by EED, for one year; values below 0 indicate heat extraction from the ground (heating for the building and DHW).



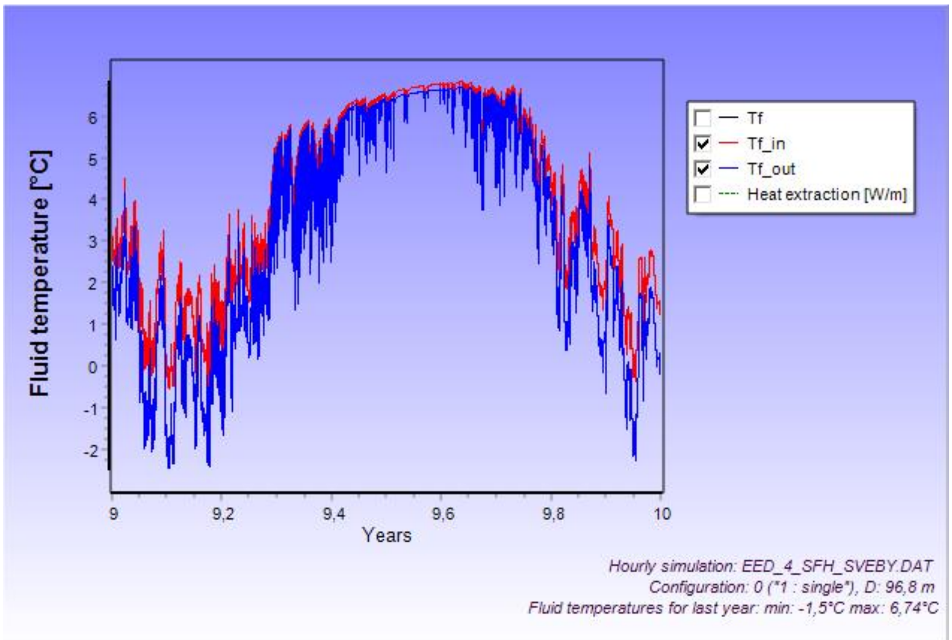
Graph of hourly load data as prepared by EED, repetition of first year data for 10 years

When using “Solve mean fluid temperature”, the temperature development based on the data given in the drop-down menus and the input file is calculated over the given time (10 years). The temperature values are mean temperatures inside the BHE, with the inlet to the BHE lower and outlet from the BHE higher in heating mode (and vice versa in cooling mode). The temperature level exhibit a noticeable decrease during the first 3-4 years after which further decrease is rather small. The minimum value reaches -1.5 °C.



Graph of fluid temperature development (Tf) for 10 years

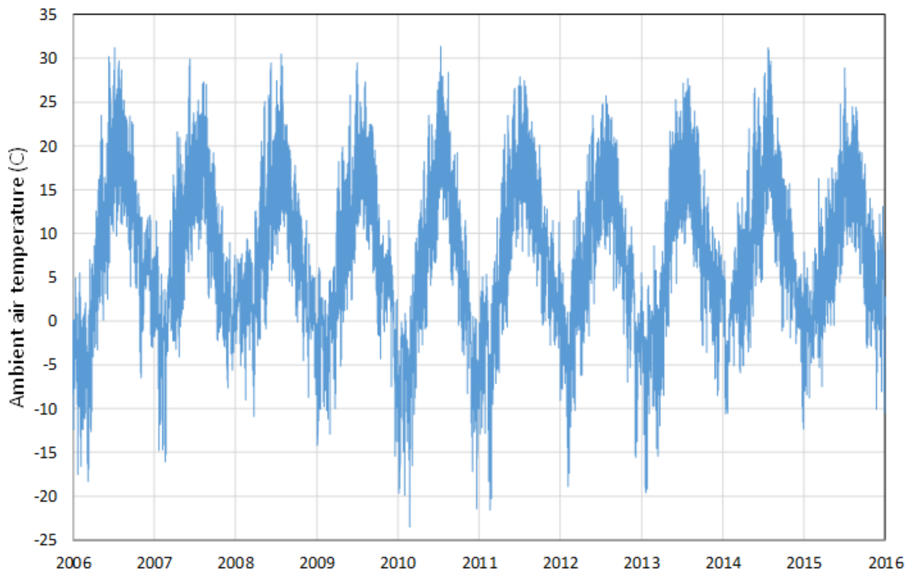
The temperatures of the fluid entering the heat pump or building system (Entering Water Temperature EWT) and the fluid exiting the heat pump or building system (Leaving Water Temperature LWT) are displayed in the next figure for year 10.



Graph of fluid temperature development (Tf_in for EWT and Tf_out for LWT) for year 10.

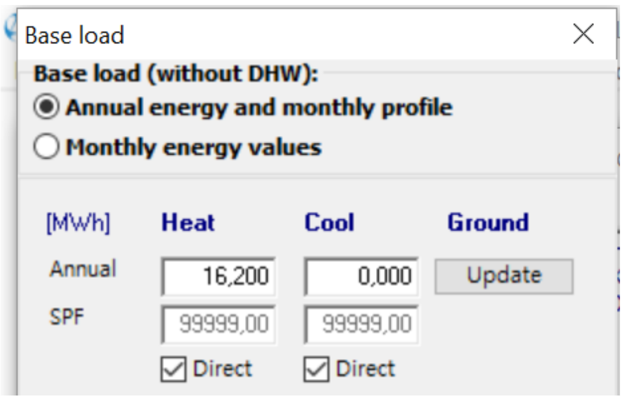
Results for 10 year hourly data (2006-2015)

Filename for sample input file: EED_4_SFH_SMHI.dat
Filenames for sample data files: EED_4_SFH_SMHI_space.txt
EED_4_SFH_SMHI_dhw.txt



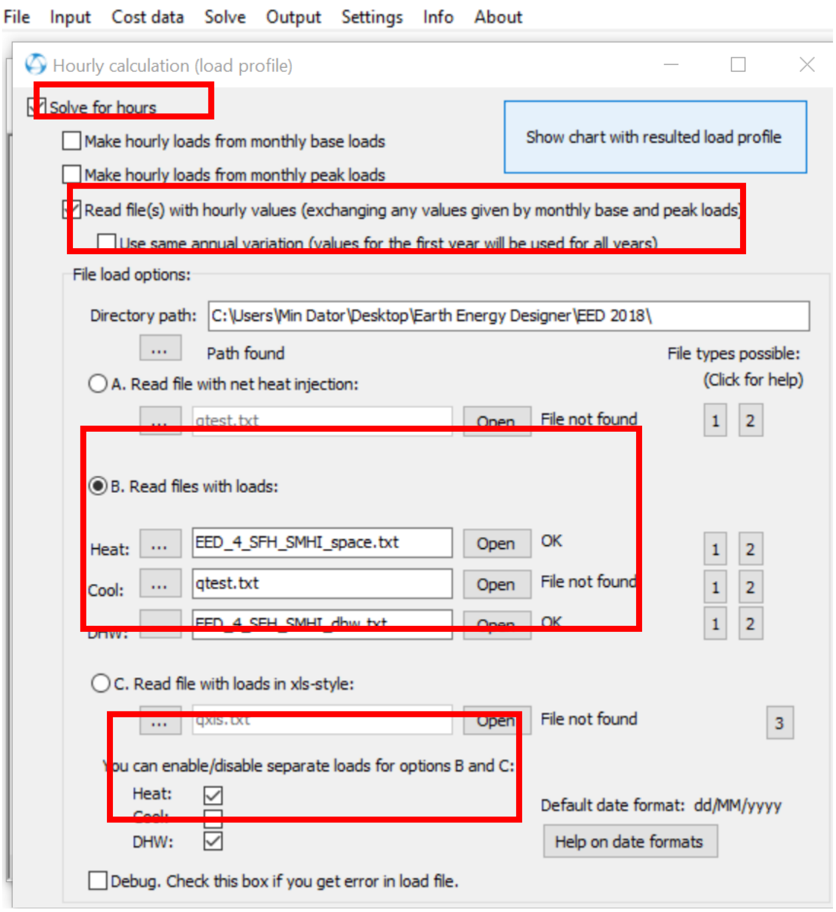
Graph of actual ambient air temperature in Stockholm during the period 2006-2015.

The climate data is used to generate one file for the ground load due to space heating and one file for the ground load due to domestic hot water production. In order to use ground loads the boxes "Direct" is clicked in the "Base Load" submenu. No other values in the "Base Load" and "Peak Load" submenus will be used when hourly loads have been chosen.



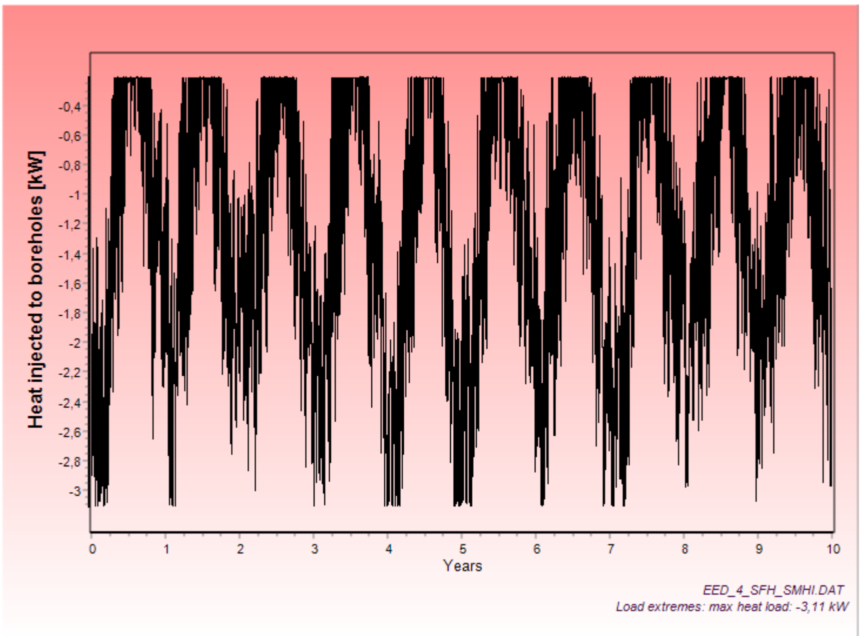
Click the boxes "Direct" if data for ground loads are given.

The option for "Hourly Calculation (load profile)" is chosen, with the respective drop-down menu (also opening through key F8). Option B with separate load files for heat and DHW is used. See screen sample below with relevant items highlighted.



Click the relevant boxes for hourly calculation without annual repetition of data.
Give file names for heat and DHW loads.
[Ps. You need to give your own directory path]

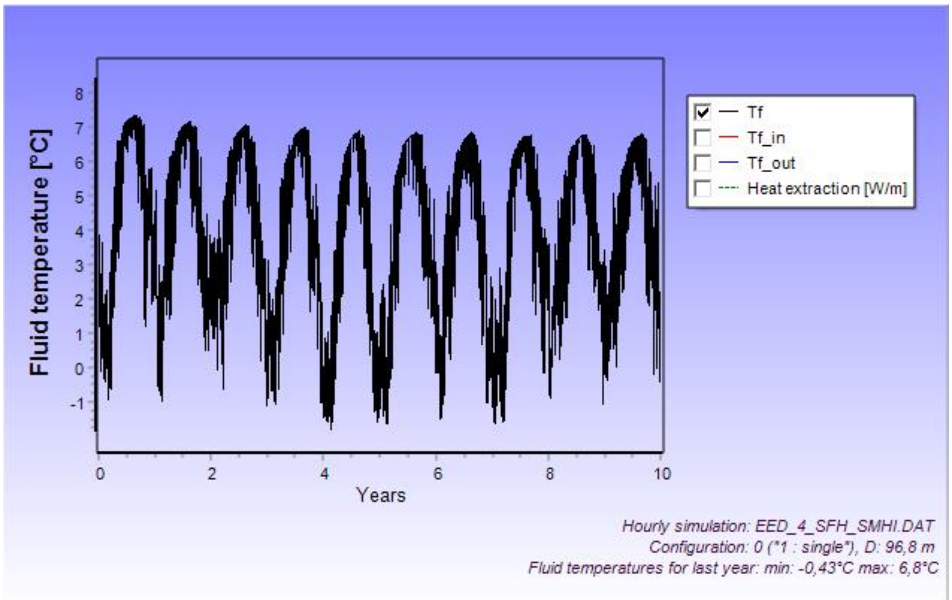
The files contain data for ten years, and the load curve resulting from this file is shown below.



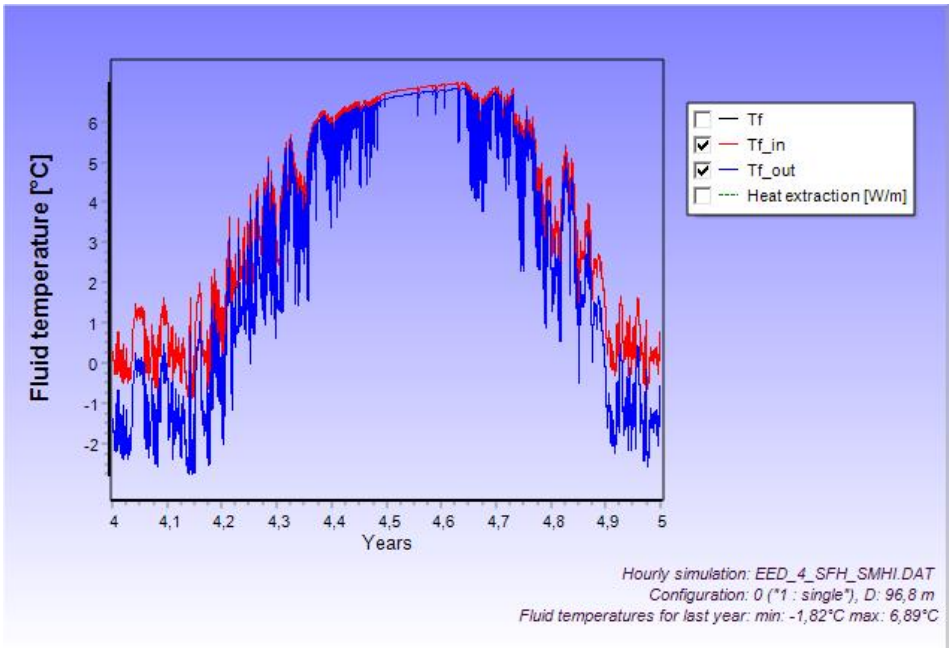
Graph of hourly load data for 10 years.

The calculation in this case does not allow the simulation time to exceed the duration of the provided hourly data. The average value of annual ground heat loads is 8129 kWh for space heating and 2702 kWh for domestic hot water production. The highest annual ground heat load for space heating is 9218 kWh for the cold winter 2009-2010.

When using “Solve mean fluid temperature”, the temperature development based on the data given in the drop-down menus and the input file is calculated over the given time (10 years). The temperature values are mean temperatures inside the BHE, with the inlet to the BHE lower and outlet from the BHE higher in heating mode (and vice versa in cooling mode). In this case the fluid temperature development reflects the variation in climate with especially low temperatures during the winter 2009-2010, 2010-11 and 2012-2013. The lowest fluid temperature, -1.8 °C, is obtained during the 5th year (winter 2009-2010).

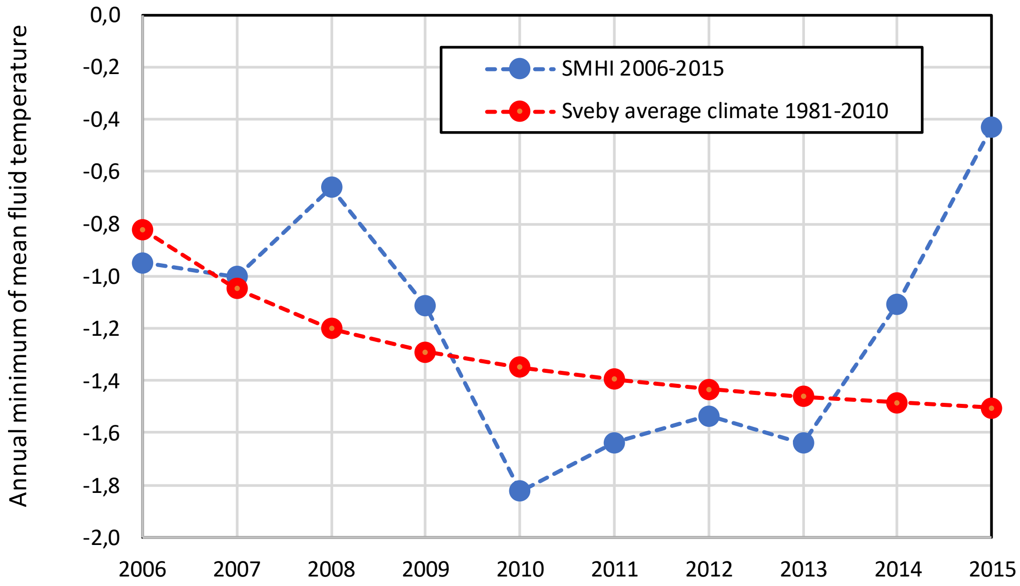


Graph of fluid temperature development (Tf) for 10 years



Graph of fluid temperature development (Tf_in for EWT and Tf_out for LWT) for year 5, which is the coldest. (To obtain this figure set simulation period to 5 years and show results after 4 years.)

A summary of the computed minimum fluid temperatures for the two cases is shown below. The characteristic gradual decrease observed for a Nordic ground-source heat pump resulting from a calculation with a repeated annual load, as in the case with normalised weather data (Sveby), is not seen with the actual weather data (SMHI) where the last year happens to be the mildest. The average minimum fluid temperature over the ten years is -1.3 °C for the repeated normal year case (Sveby) and -1.2 °C for the ten year data case (SMHI). The minimum fluid temperature is -1.5 °C and -1.8 °C for the Sveby and SMHI case respectively.



Graph of annual minimum fluid temperature during the simulation period for the case of a ground load based on a repeated average climate (10 times the normalised annual data as to Sveby) and ten year (2006-2015) real data from the Swedish Meteorological & Hydrological Institute (SMHI).