

HFC Manual

HFC stands for Heat Flux Calculator and is a software package developed by SWT Aachen in cooperation with the Shock Wave Laboratory of RWTH Aachen University.

The program has been developed to offer an easy way for calculating the heat flux from temperature signals of heat flux gauges and supports the heat flux determination with coaxial thermocouples with additional back wall temperature measurement.

The current version of HFC contains an analytical algorithm for short time measurements and a 1D numerical algorithm for evaluating long time measurements.

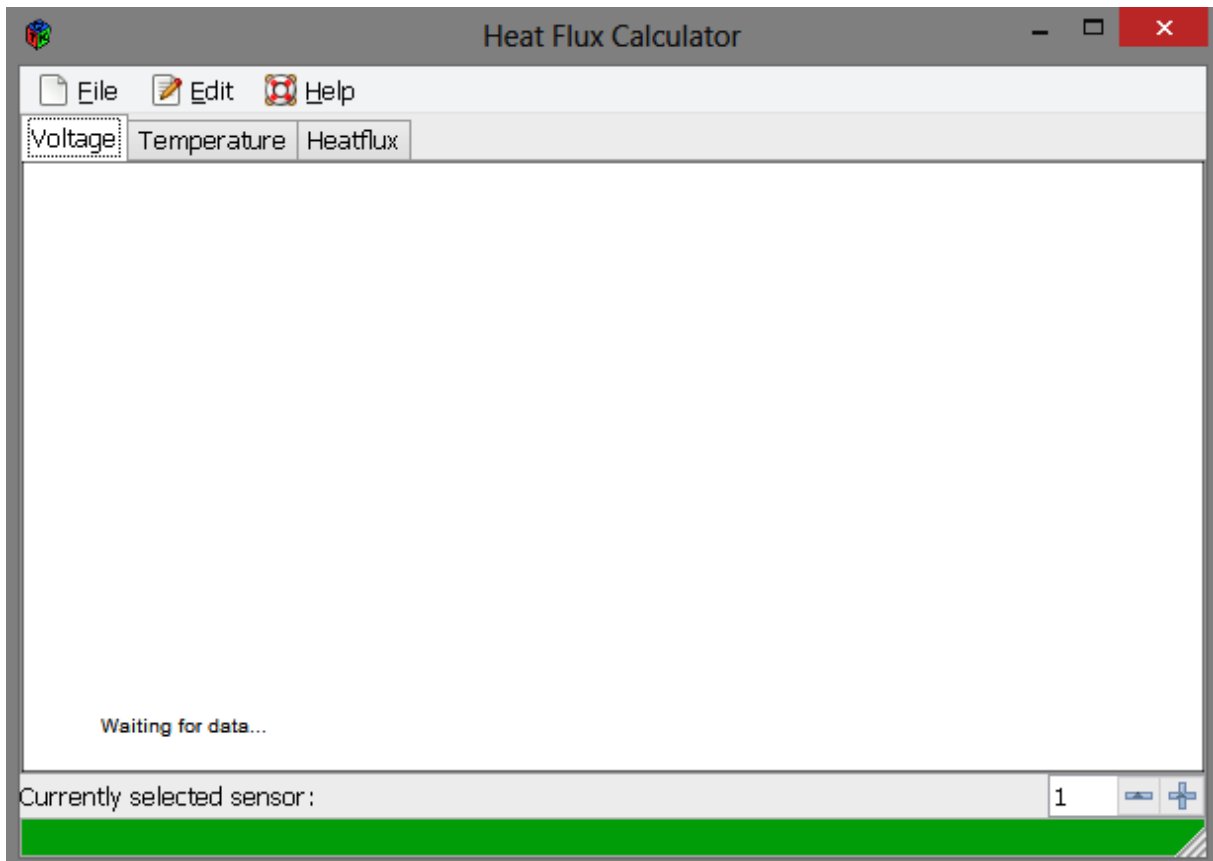
Additionally HFC makes use of a graphical user interface to ease the data evaluation process.

Features:

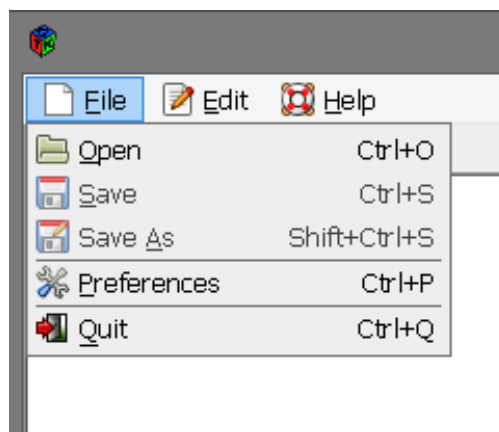
- Calculation of heat fluxes for gauges based on the principle of semi-infinite thick bodies for short measuring times and for gauges with additional back wall temperature measurement
- Input data can be voltages directly from the measurement device or temperatures
- Easy to use graphical user interface

Structure of the graphical user interface

The following parts of this manual focus on HFC running under Windows.

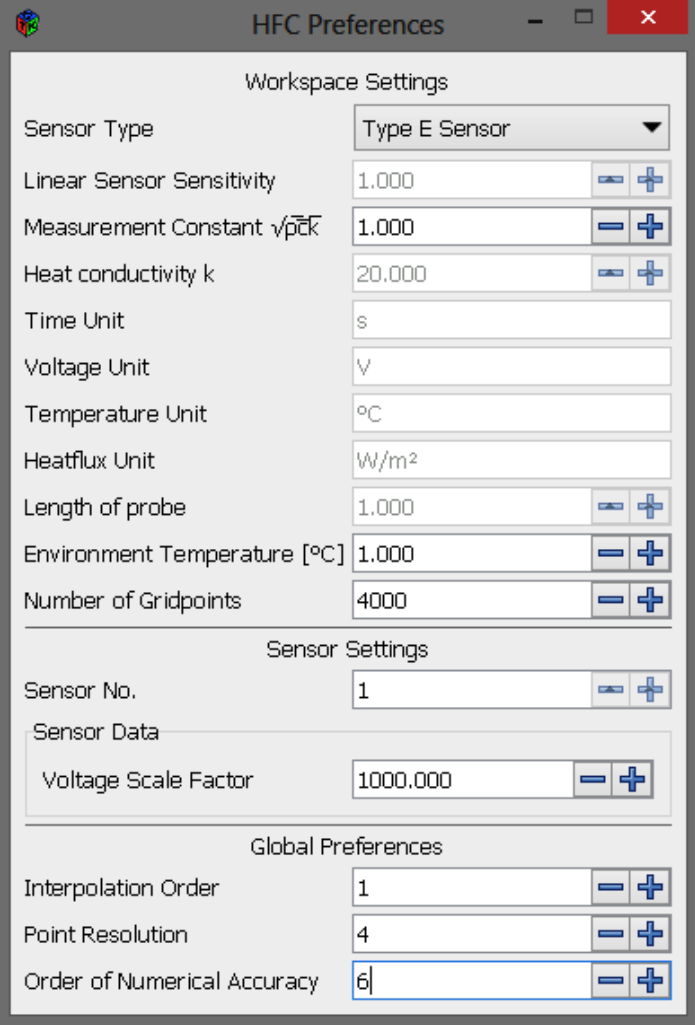


The screenshot above shows the main window of HFC after its initial start. As seen in the lower left corner HFC is <Waiting for data...>.



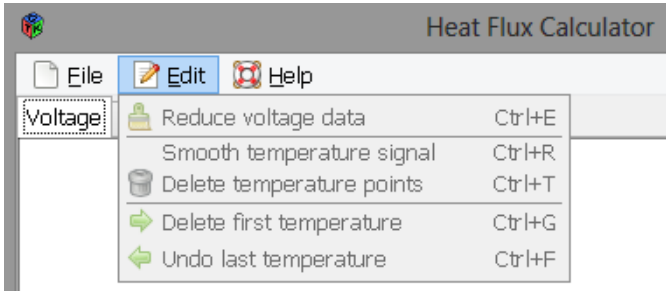
The menu bar consists of the main items <File> and <Edit>.

The <File> option allows to load a data set and to save current results of the data evaluation and settings of HFC. All values mandatory to calculate the heat flux are defined in <Preferences>. The following screenshots shows the <Preferences> window.

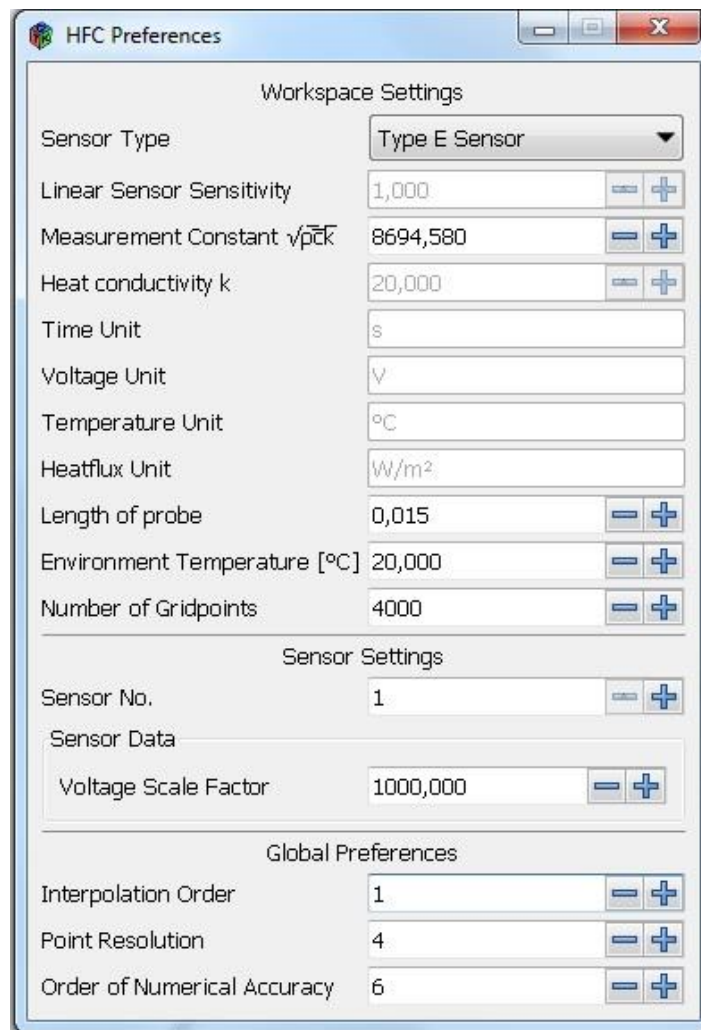


The second menu bar item <Edit> offers several options of adapting the voltage and temperature data sets according to your requirements.

All entries under <Edit> are used for reduction, smoothing and preparing the dataset for the calculation of the heat flux. Details of this will be discussed at a later stage of this manual.



Configuring HFC



The HFC <Preferences> window offers most of the important settings needed for a correct calculation of the heat flux.

Workspace Settings

All data in the workspace settings as well as in the input files has to be given in SI-units. The characters “,” and “.” are equivalent for decimal point.

Sensor type:

This dropdown menu allows selecting the thermocouples sensor type, i.e. type E or type K. In this case the temperature is calculated from the voltage signal using a polynomial fit for the temperature dependence according to the NIST Database valid up to 1000 °C.

The option ‘Thin film Gauge’ allows the calculation of the heat flux history from a voltage signal measured by a semi-infinite body, i.e. the measuring gauge has to fulfill

the requirement of a semi-infinite body, i.e. measuring times have to be sufficiently short. Furthermore, for the option 'Thin film Gauge' in the workspace settings the value of the 'Linear Sensor Sensitivity' has to be given.

Linear Sensor Sensitivity:

This value is needed for thin film gauges. It holds for a constant temperature sensitivity. In this case the linear factor is calculated from the following values:

R_0 : The resistance of the thin film at $T = 273K$; calibration value

α_0 : Temperature sensitivity; calibration value

I_{amp} : The current of the thin film gauge during the measurement

$$\text{Linear Sensor Sensitivity} = \frac{1}{R_0 \cdot \alpha_0 \cdot I_{amp}}$$

The Linear Sensor Sensitivity has to be given in the unit K/V .

Measurement Constant $\sqrt{\rho ck}$:

For the heat flux calculation the thermal material properties of the sensor have to be given as $\sqrt{\rho ck}$ -value,

ρ = material density

c = material heat capacity

k = material heat conductivity

The $\sqrt{\rho ck}$ -value is determined by a special sensor calibration technique and usually provided by the sensor manufacturer. The unit of the $\sqrt{\rho ck}$ -value is $\frac{W \cdot \sqrt{s}}{m^2 k}$.

Displayed Units:

Length of the probe:

The length of the probe has to be given in case of making use of the back wall temperature measurement for coaxial thermocouples. It is the distance between the front surface and the backward temperature measuring position.

Environment Temperature [$^{\circ}C$]:

For calculating the correct temperatures from the voltage data the environmental temperature sensor temperature at the beginning of the measurement has to be given in degree Celsius.

Number of Gridpoints:

This option is used for long measurements with a coaxial thermocouple with additional back wall temperature measurements. In this case the probe length is discretized by the given number of grid points. For thermocouples up to 20 mm length 3000 to 4000 grid points are recommended.

Sensor settings:

Sensor No.:

Number of the measurement location in case of a coaxial thermocouple with back wall temperature measurement (1 = front surface; 2 = back wall position).

Voltage Scale Factor

For thin film gauges this factor is one over the voltage amplification rate used for the measurement. For thermocouples type E or K this factor is given by converting the voltage signal from V into μV (10^6) divided by the chosen amplification rate. For an amplification rate e.g. of 100 the Voltage Scale Factor would be 10000.

Global Preferences

Interpolation Order:

The Interpolation order defines how the discrete data points are displayed. Interpolation order 0 means all data points are connected stepwise. Interpolation order 1 means all data points are linearly connected. Interpolation order 2 means all data points are represented by a second order polynomial, etc.

Point Resolution:

Distance of pixels at which the plot is evaluated; smaller values imply higher resolution.

Order of Numerical:

Given as negative power to 10, characterizing accuracy of numerical iterations.

Structure of the input file

The input file consists of a simple ASCII text file with a simple formatting. The input file is a comma separated file with a header (blue) and a data section (red). The header describes in which sequence the data point is stored. The time is indicated by t , the voltage of the front sensor by $u1$ and of the back wall sensor by $u2$. For classical short-time measurements the data reduction is performed utilizing the principle of a semi-infinite thick body. In this case the input data file contains the time and the corresponding voltage or temperature data of only the front sensor.

For long-time measurements the option of an additional back wall temperature measurement can be chosen.

The following is an example of an input file of gauge with front and back wall temperature measurement:

```
t,U1,U2  
0,-0.005107286,-0.003936367  
0.01,-0.002665286,0.004608633  
0.02,-0.000224286,0.002167633  
0.03,0.003437714,-0.000274367  
0.04,-0.000224286,0.000946633  
0.05,0.002216714,0.003387633
```

The following example shows the structure of the input file, if the temperature is given as input data.

```
t,T1,T2  
0,20.012697,20.005749  
0.01,19.951138,19.985322  
0.02,19.948684,19.986269  
0.03,19.94603,19.986751  
0.04,19.945731,19.986645  
0.05,19.945929,19.986943
```

The maximum amount of data points depends on the available memory. For sensors without back wall temperature measurement only the front temperature $T1$ has to be given. In case of any problems concerning the heat flux calculation, for large input files it is recommended to reduce the amount of data and for noisy signals to smooth the temperature signals before performing the heat flux calculation.

For the heat flux calculation it doesn't matter whether the temperature is given in degree Celsius or in Kelvin. For sake of simplicity the legend of the temperature axis is only in degree Celsius despite the fact that the temperature in the input file might be given in Kelvin.

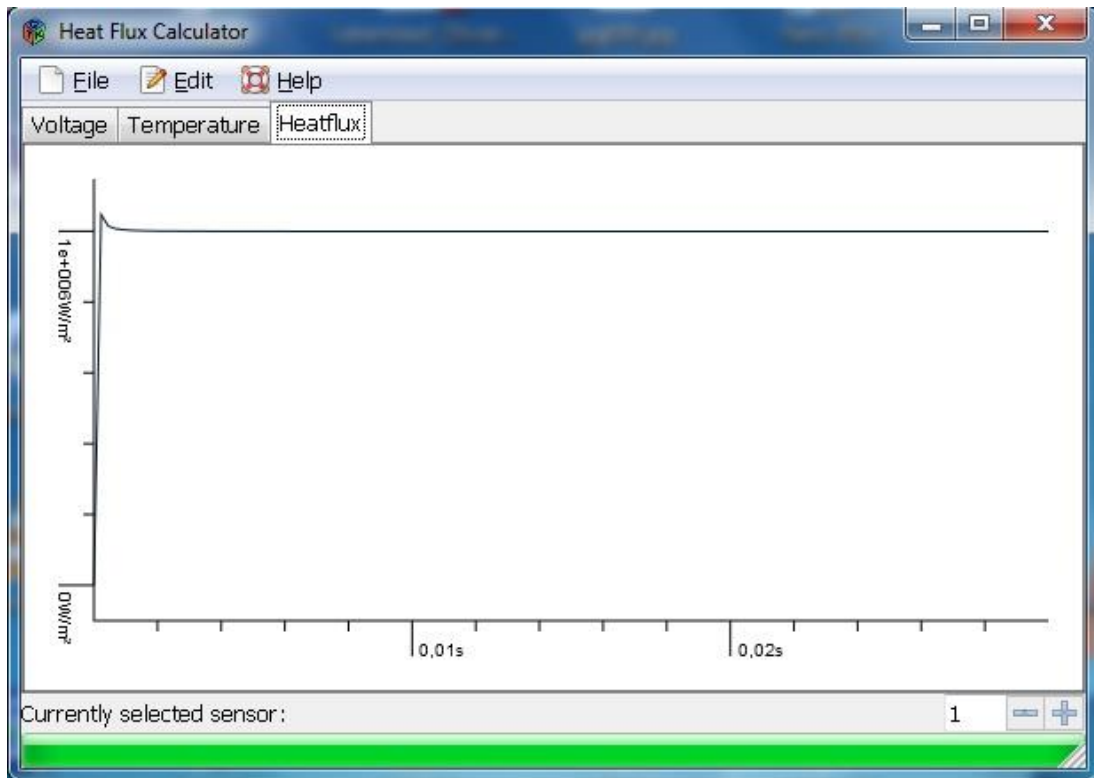
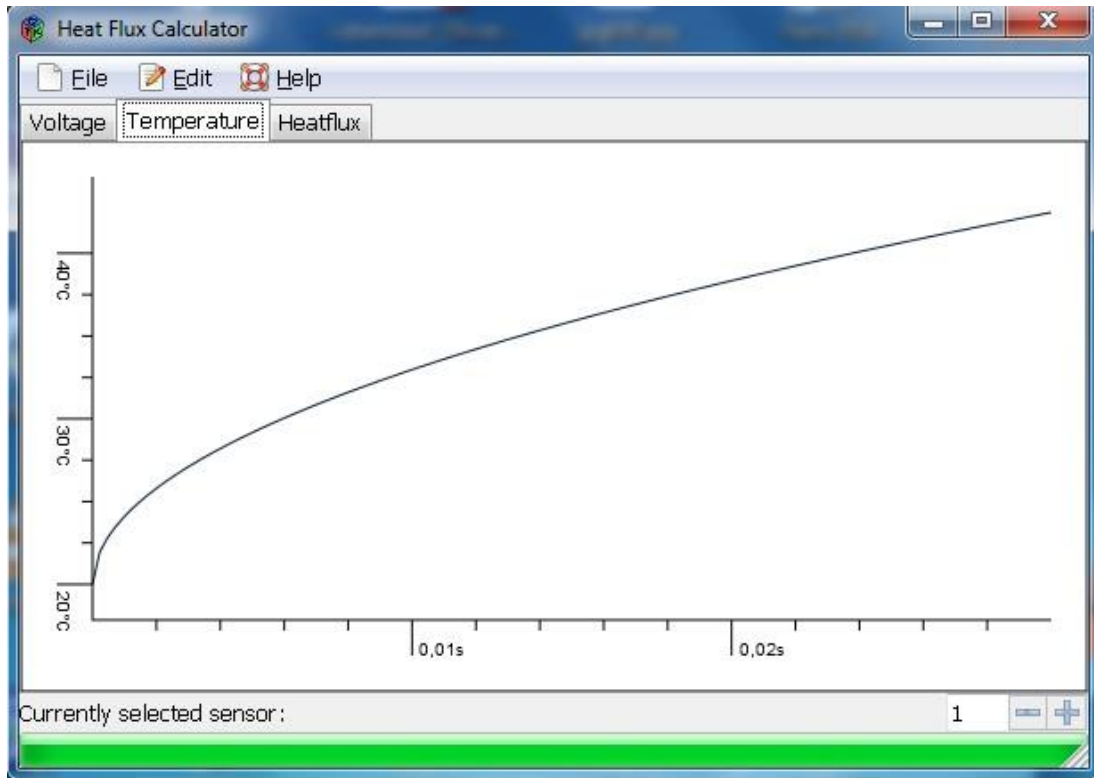
Execution of HFC

At first set the necessary values in <Preferences>. After this, click on the <File> button and then <Open> to load the input file. The software package contains sample data sets which in the following are used to demonstrate the features of the method. The first dataset 'HFC_sample_Laplace.dat' is typical for the standard short-time measurement based on the temperature signal of the front sensor surface. The data file only consists of the time and the temperature signal data. After loading the data file click on <Preferences> for choosing the settings. In the first line the sensor type has to be given. One can choose between a type E, type K sensor and a thin film gauge. Depending on the selection of sensor type the heat conductivity k is prescribed. In the third line the $\sqrt{\rho ck}$ -value, which usually is given by calibration of the sensor is entered.

The sample data set already gives the temperature signal, which in this case is a theoretically generated signal is resulting in a time constant heat flux. There is no voltage data in this case. Click on the <Heat flux> tab to start the computation and to display the resulting heat flux history. In this case the heat flux is constant with time.

Its theoretical value is directly proportional to the $\sqrt{\rho ck}$ -value $\left(\dot{q} = T_s(t) \cdot \sqrt{\frac{\pi}{4} \cdot \frac{\rho ck}{t}} \right)$.

For the example shown below, the same preferences were used as they are shown on page 4.



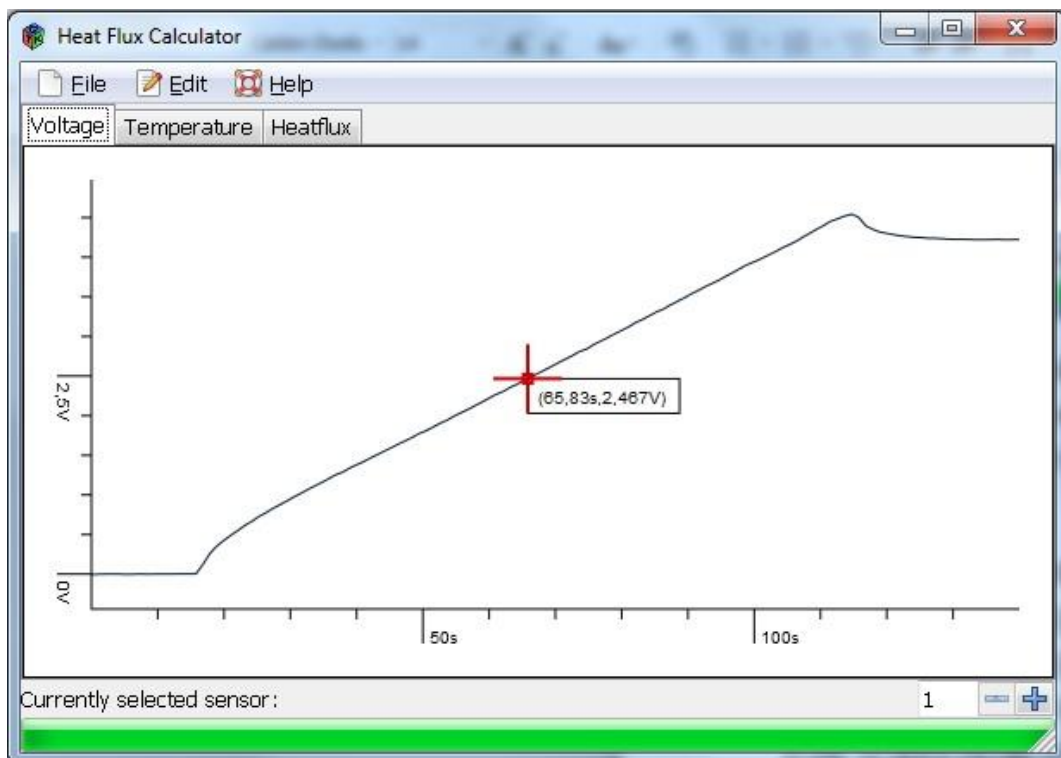
Another sample file delivered with HFC typical for the case with back wall temperature measurement is named 'HFC_sample_Voltage.dat'.

The first few lines of the ASCII text of the input file have following structure:

```
t,U1,U2
0,-0.005107286,-0.003936367
0.01,-0.002665286,0.004608633
0.02,-0.000224286,0.002167633
0.03,0.003437714,-0.000274367
0.04,-0.000224286,0.000946633
0.05,0.002216714,0.003387633
0.06,-0.000224286,0.000946633
```

The order of entries is: time step, voltage sensor 1 and voltage sensor 2.

Choose the menu item <File>, select <Open> and load the sample input file into HFC. After loading the file the main window looks like the following screenshot showing the voltage signal of the front surface sensor (sensor 1).



With 'Currently selected sensor' one can switch between sensor 1 (front wall) and sensor 2 (back wall measurement position).

The item <Edit> in the menu bar includes several options of data processing of the voltage and temperature signal before the heat flux calculation is performed.

Reduce voltage data:

This option allows reducing the number of voltage data points according to the selected number. Reducing the number of data points does not result in a reduction of the overall time period. To get back to the full signal, the original data file has to be reloaded.

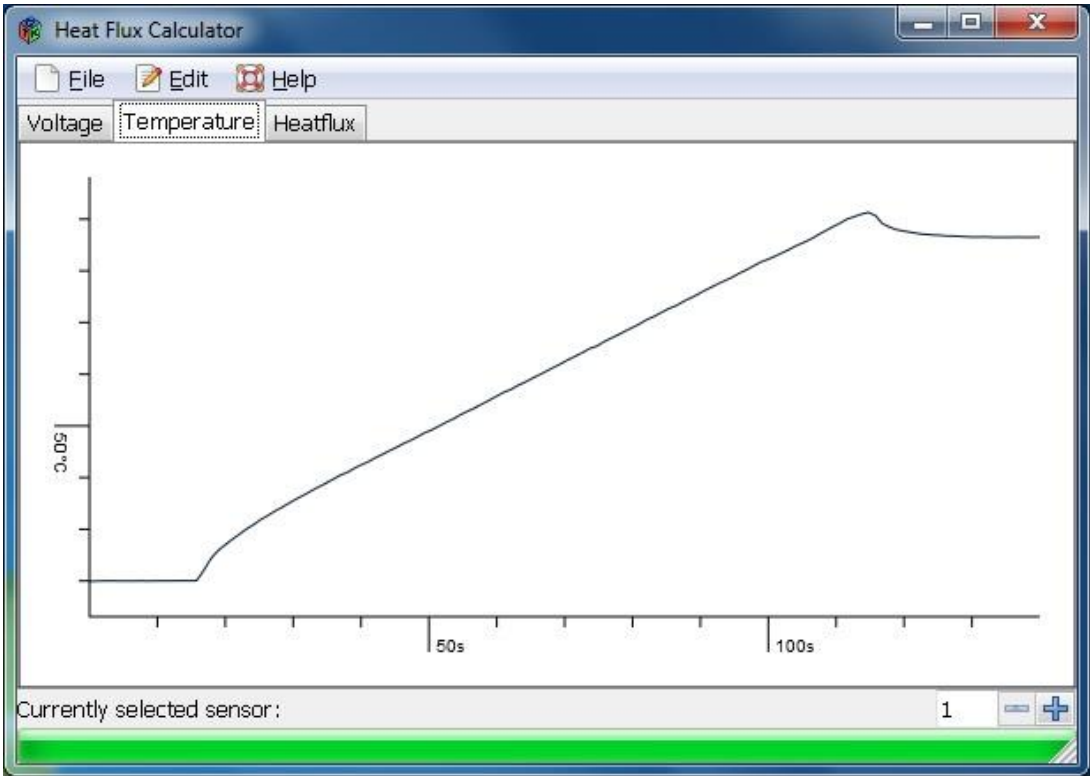
Smooth temperature signal:

The 'Smooth temperature signal' button enables a smoothing of the temperature signal before the heat flux calculation is executed, which is advisable for noisy signals. After selecting this option, in a corresponding window a smoothing radius has to be selected with "+" and "-" button. Large radii result in a strong smoothing and vice versa. The smoothed temperature signals are plotted on top of each other. The last temperature signal is the actual one which is used for the heat flux calculation. With the button 'Delete first Temperature' the first (original) and subsequently the following temperature signals can be deleted. The 'Undo last temperature' button enables to remove the last and following processed temperature signals.

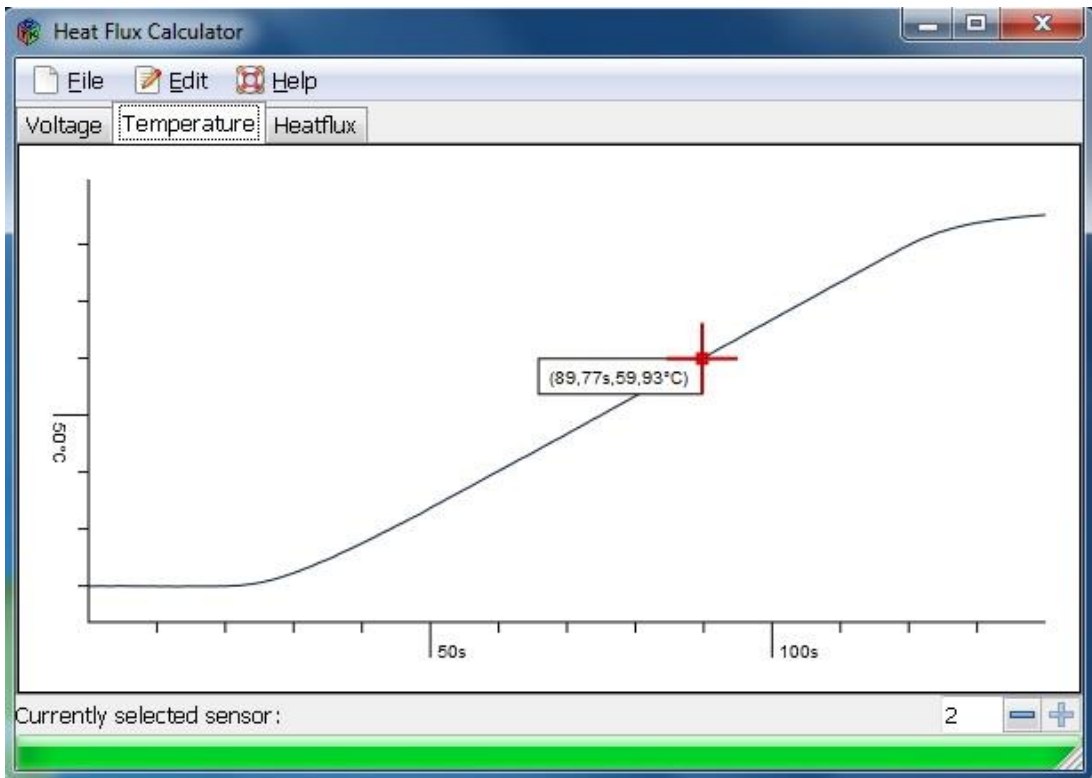
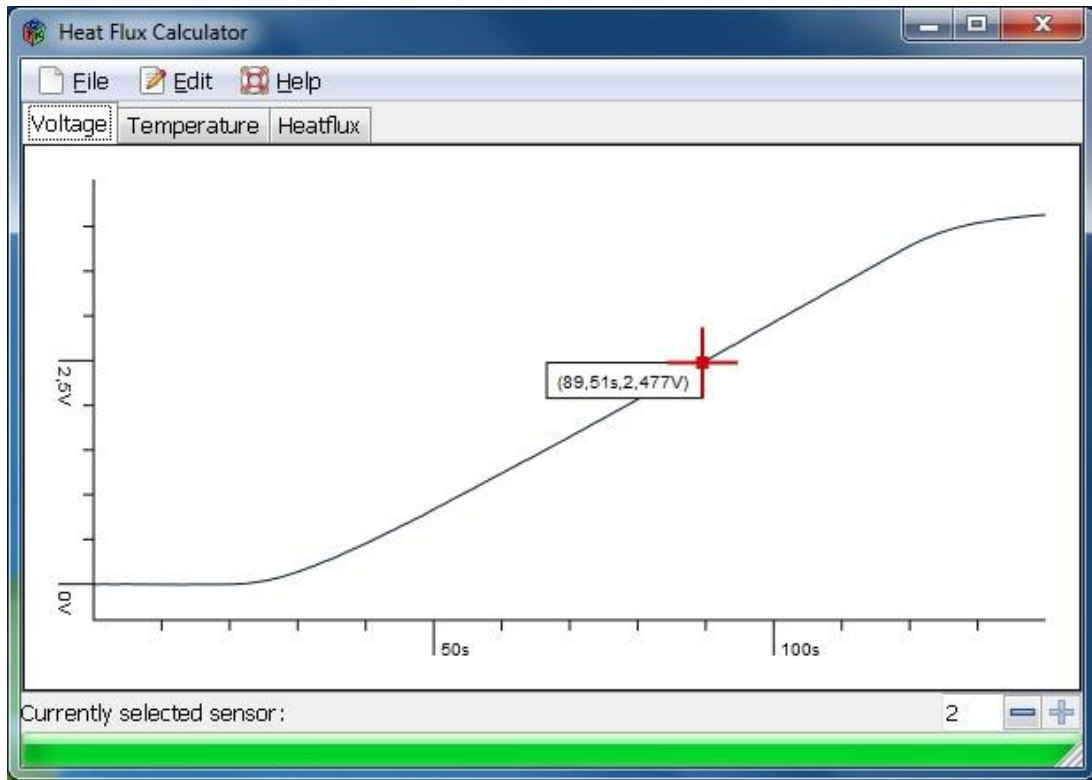
Delete temperature points:

By pressing the left mouse button on the temperature graph and moving the cursor to the left or to the right, data points are selected for further processing within the chosen time window. Pressing the 'Delete temperature points' button connects the first and the last data point of the selected time window linearly. This option allows removing e.g. unphysical spikes in the signal as they may occur due a high voltage discharge during the measurement.

After clicking the <Temperature> tab the actual temperature history is displayed:



The temperature signal of sensor 2 is generated in the same way choosing the <currently selected sensor> in the lower part of the window. In case that the temperature signal has been modified by e.g. smoothing or changing the sensor sensitivity, press the <Delete first temperature> button to display the actual temperature signal.



The heat flux calculation starts automatically just clicking the <Heatflux> tab and either the progress bar is indicating the progress of the calculation or the final result is directly shown. For further post-processing the data can be stored in the <File> menu.

