HFM1
Heat Flux Meter

October 2014

Contents

1.   Introduction

The HFM1 Heat Flux Meter is a complete system for collecting and storing data from up to ten Sensors in the field or laboratory. The HFM1 is equipped with an internal battery which provides power to the instrument as well as the sensors. A fully charged battery should have the capacity to provide several hours of data collection in the field before recharging is required. Depending on logging interval, the internal battery can also last several days.

There are three parts to the HFM1 system:
1.   The instrument (also known as the data logger).
2.   Break-out box for connection between the sensors and the instrument.
3.   Sensor

The system is plug-and-play in that it is ready to go from the box. You will need to plug a sensor into a vacant channel, assign a logging interval, and connect external power supply to the instrument.

The output from the sensors is W/m^2 for the HFP01 Heat Flux Plate sensors and °C for the thermistor sensors. The mV data are the raw data from the sensors. The calculated data are derived from either a lookup table or user script supplied with the HFM1 from ICT International.

This manual outlines how to start your HFM1 and connect power supply. It also shows how to download data and configure your instrument.

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2. System Requirements

2.1 CPU Processor

The ICT Instrument software does not require large processing
power. For example it is compatible with NetBooks.
Minimum Recommended Processor Capacity:
Intel Atom Processors with a CPU N270 @ 1.66 GHz and 1GB RAM or higher.

2.2 Software

The ICT Instrument software is compatible with the following Windows
Operating Systems:
a.   Windows XP
b.   Windows Vista
c.   Windows7
d.   Windows Virtual OS run from a Mac computer

2.3 Screen Resolution

The ICT Instrument software is written to a fixed screen resolution of 857 x
660 dpi (it does not Auto Resize) and works best on current model laptops
that have a screen size of 11.6'' or larger and a default screen resolution of
1366 x 768 (the vertical height of 768 being most important otherwise you
can't see the bottom of the software).

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3. Charging the HFM1 Internal Battery

The HFM1 is a self contained instrument that incorporates a lithium polymer battery. Before using the instrument, this battery MUST be charged. To choose from a range of charging options see Connecting a Power Supply to the Instrument (pages 6 to 11).

You can see a demonstration video on how to turn on and connect power supply to your instrument via this link: http://www.youtube.com/watch?v=S5OsGL7Wj-8

The HFM1 has an internal battery which can supply power for several hours to days depending on frequency of use. It is recommended to charge the internal battery with a solar panel, solar panel battery pack (SPBP) supplied by ICT International, or in the lab or glasshouse with a CH24, 12V, power supply.

An external power supply can be connected to the HFM1 in the field. See Connecting a Power Supply to the Instrument (Field Operation) (pages 10 & 11) for more details.

The unique power-bus plug design was developed by ICT International to simplify the electrical wiring process. It minimises the need for custom tools in the field requiring only that the outer cable sheath be stripped back to expose the copper wire.

As shown in Connecting a Power Supply to the Instrument (page 6) no other tools are required with all necessary components and fixings fully incorporated into the instrument design. Retaining straps ensure the power-bus plugs do not separate from the instrument when removed from the power-bus during wiring preparation and connection of external power.

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3.1 Connecting a Power Supply to the Instrument
3.1.1 Individual Power Supply Connections

Important: Do not connect external power until the final step

① Remove both ICT Bus plugs from either end of the sensor.

② Unscrew the end of the plug 1 to 2 turns.

③ Remove the Bus plug sealing cap.

④ Insert either polarity of the external power source cable.

⑤ Strip a maximum of 15mm from the end of the cable.

⑥ Pull the cable back so only that the stripped wires protrude from the ICT bus plug.

⑦ Bend the stripped wires back over the end of the ICT bus plug.

⑧ **Important** : Seal the cable against water ingress by tightening the end of the plug.

⑨ **Repeat for second bus plug**

Insert the ICT bus plugs into the endcap of the sensor. The plugs can be inserted in either polarity and will click when seated into position.

⑩

External power options

1. 12V Solar panel only
2. 12V Solar panel and battery
3. 12V DC power supply

Connect the power cable to the external power source.

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3.1.2   Shared Power Supply for Multiple Instruments

Unused Bus plugs MUST have the plug sealing cap installed to prevent water from entering the device.

! Positive cable inserts on the left
! Negative cable inserts on the right.

Power can be daisy-chained from either end of the device to connect power to other devices

External power can be connected radially from a central distribution hub. Alternatively , the external power can be connected directly to a single unit

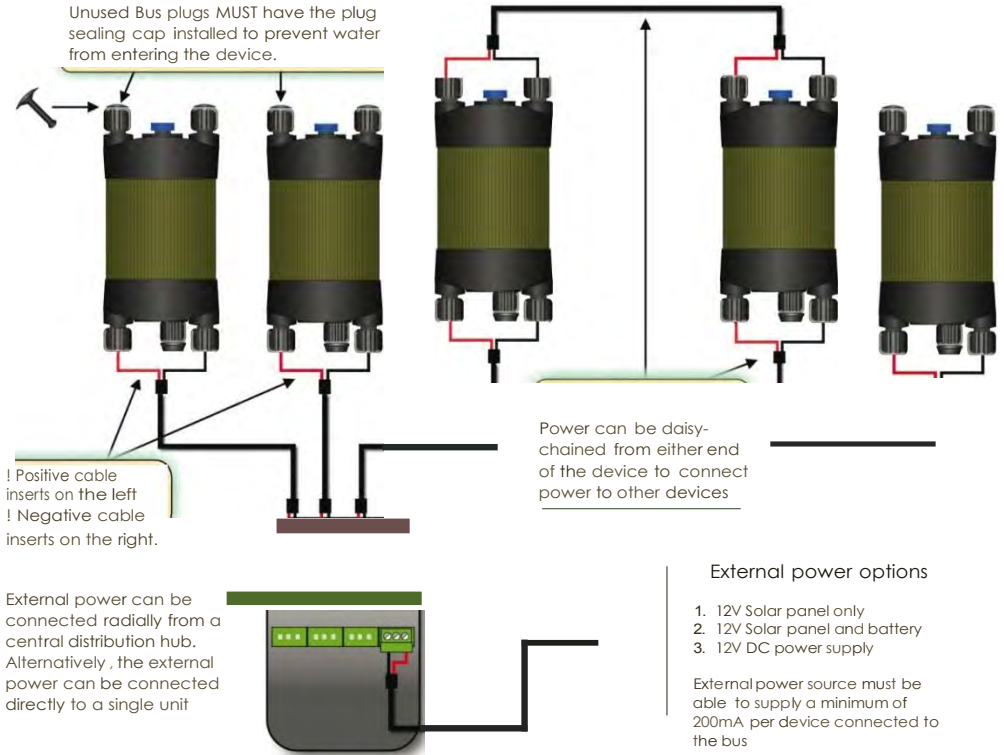### External power options

1. 12V Solar panel only
2. 12V Solar panel and battery
3. 12V DC power supply

External power source must be able to supply a minimum of 200mA per device connected to the bus

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3.1.3 Connecting Power via USB cable to a laptop/PC

HFM1

Laptop/PC

USB Cable
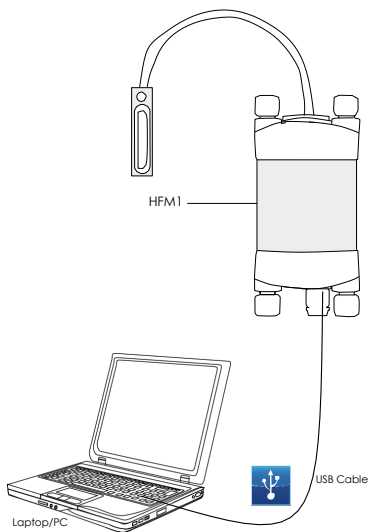
3.1.4 Connecting Power Directly via CH24 Power Supply

HFM1

CH24 Power Supply
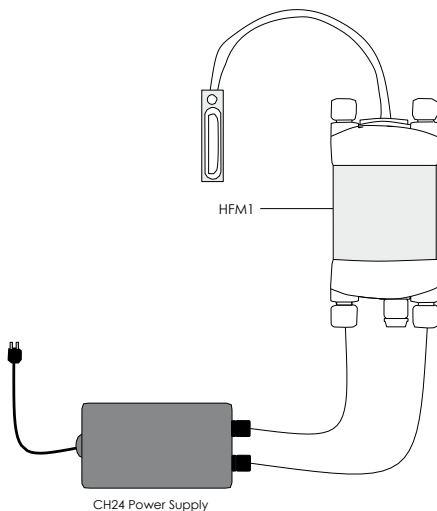
3.1.5 Connecting Power Directly via Solar Panel (Field Operation)

HFM1

Solar Panel
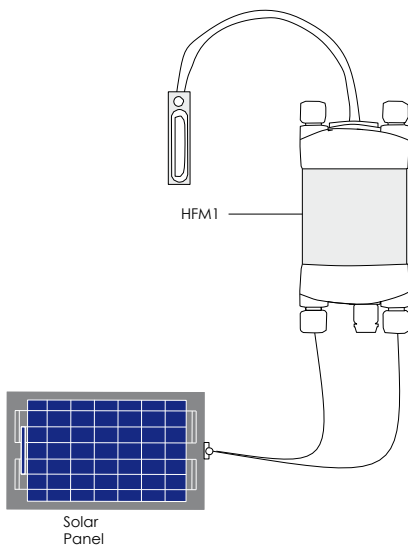
3.1.6 Connecting Power via External 12V Battery (Field Operation)

HFM1

External 12V Battery
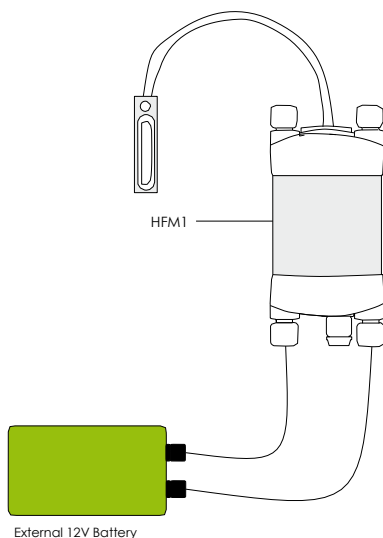
Note: The HFM1 Heat Flux Meter is non-polarized

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4. Connecting sensors to the HFM1

The sensor is connected to the logger by inserting the green connector into the appropriate channel in the break–out box supplied with the system.
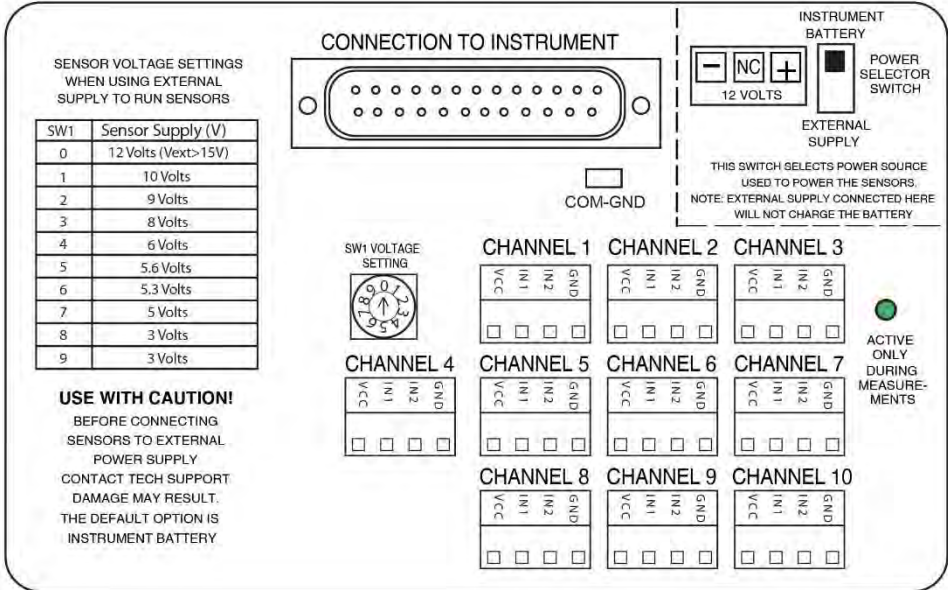
4.1 Additional Information on the Break-Out Box

When your ICT Instrument and Break-Out box arrives from ICT International you do not have to change any of the settings. The ICT Instrument and Break-Out box have already been configured for your instrument and sensors.

The Break-Out box should have the Power Selector Switch ALWAYS set to Internal Battery. This means that the power supply is coming from the ICT Instrument. If the Power Selector Switch is set to External Power then voltage is being delivered directly to the Break-Out box. If the wrong amount of voltage is supplied to the Break-Out box then you could potentially damage your sensors. External power supply is only ever used by advanced users on very rare occasions.

If on the very rare occasion you need to supply External Power, ICT recommends you consult with an ICT engineer or technician first.

If External Power is supplied to the Break-Out box, then the SW1 Voltage Setting dial becomes important. The numbers around the dial correspond to column 1 in the SW1 table printed on the Break-Out box diagram. The SW1 Voltage Setting Dial controls the supply voltage from the external power. If the dial is set to 0, then the input voltage from the external supply will be 12 Volts. If the dial is set to 1, then the input voltage from the external supply will be 10 Volts and so on. The level to which you set the input voltage will depend on your sensor specifications. ICT recommends consulting your sensor's manual, manufacturer's information, or directly contact engineers at ICT.

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5.   Install the HFM1 Software & USB Driver

Insert the supplied CD into the computer. The CD will auto-run to
present a menu. Choose software (a) then choose ICT Instrument
Installation Software (b).
The software installation will begin follow the screen prompts until the
finished installation screen appears. To install the USB driver choose USB
Driver (c) and wait for the installation to complete.

(c)
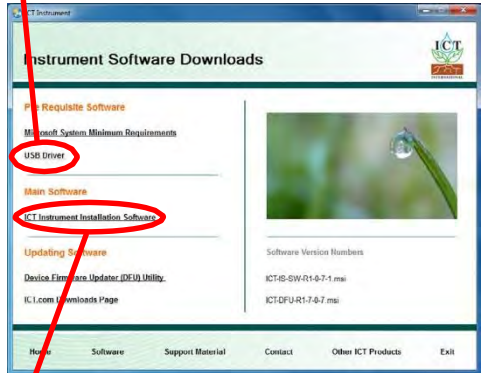
(a)   (b)

The HFM1 software can also be downloaded from the ICT International
Software Downloads Page.

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6. Turn the Instrument On

To charge and turn on your HFM1 Light Sensor Meter connect the Instrument to a computer via a USB cable. Alternatively the HFM1 can either be turned on manually by pressing the power button or automatically by connecting an external power supply.

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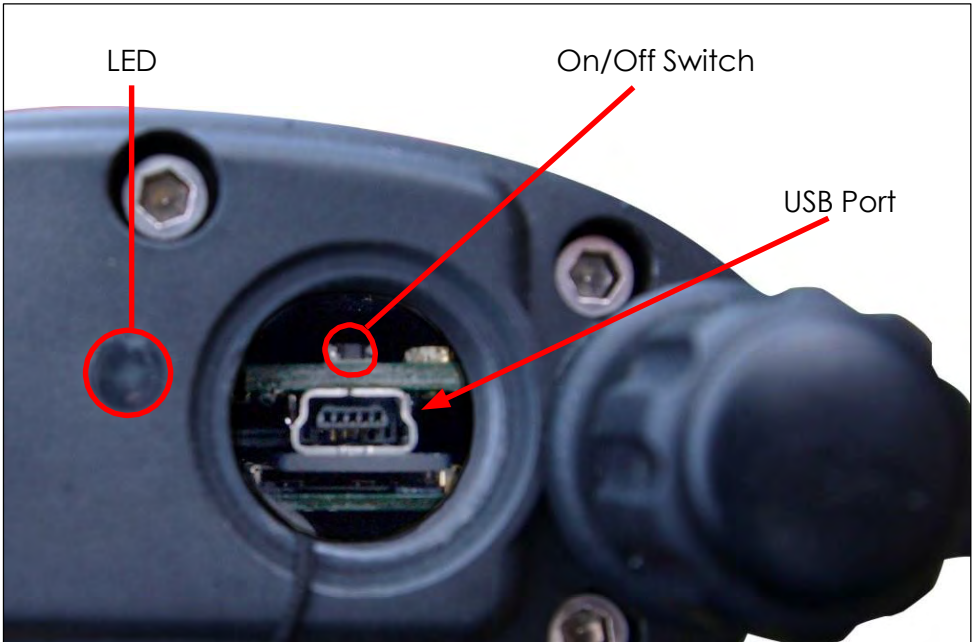
7. Connect to the Instrument

7.1 Connect Via USB

Connect the USB cable to the instrument. The LSM will automatically be detected by the computer as with any USB device. Double click the ICT Instrument icon on the Desktop to open the software and click the icon *"Connect to Instrument"*, then click *"Find Devices"* to search for the instrument and select the named instrument from the Available Devices within the Device Selection Window.
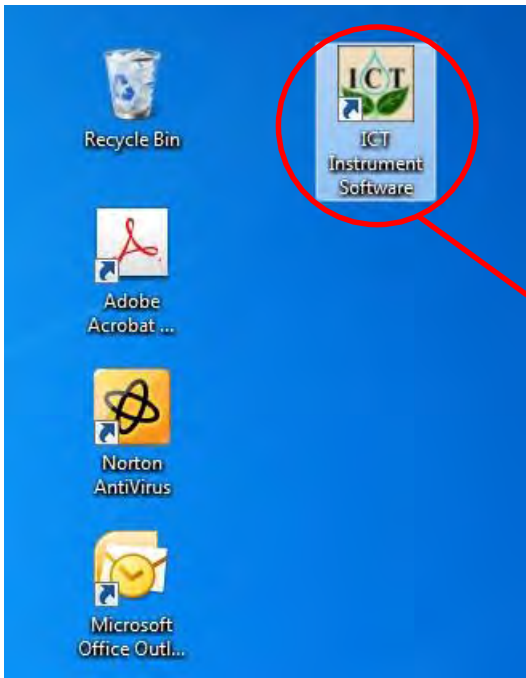
Double click the icon
"ICT Instrument Software"

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7.1.1 Software Procedure Step 1:

Click the icon *"Connect to Instrument"*

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7.1.2 **Software Procedure Step 2:**
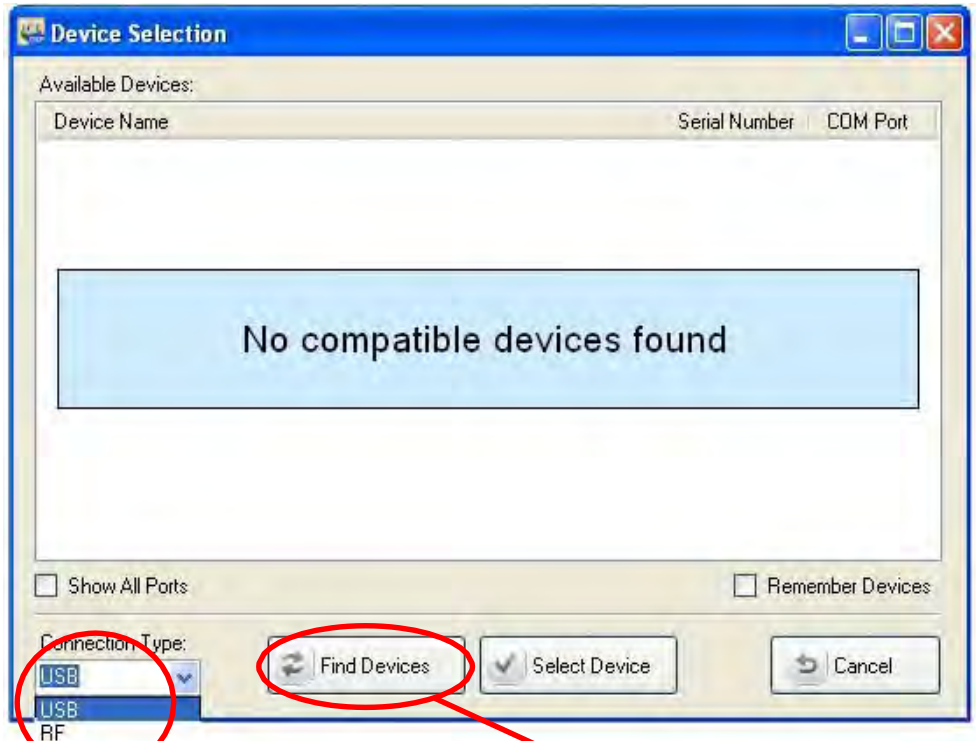
You must first choose the connection type *"USB"* then Click *"Find Devices"* to search for the instrument.

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7.1.3 Software Procedure Step 3:

Note: The software will display a message to *"Please Wait"* after which the following screen will be displayed.

You must click on device and highlight.
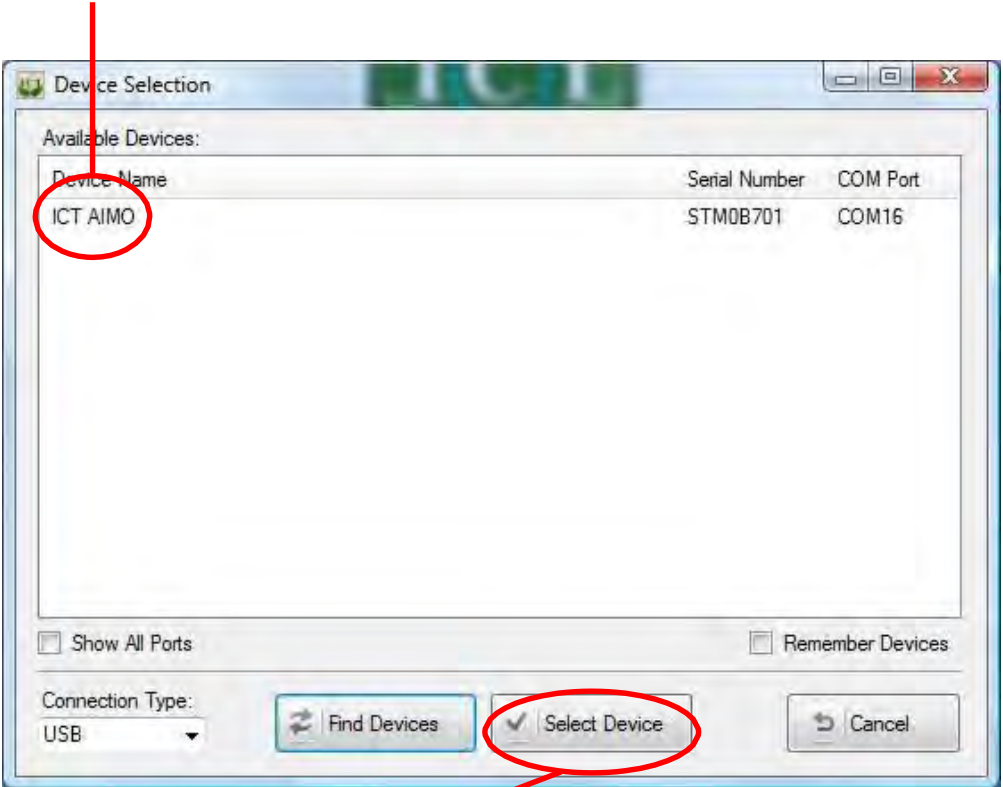
After you highlight the device then click *"Select Device"*.

7.1.4 Software Procedure Step 4:

Note: The following screens will be displayed.

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7.1.5   Software Procedure Step 5:

When the software has finished loading the instrument parameters the following screen will be displayed.

From here the measurement parameters can be set and the measurement sequence started.

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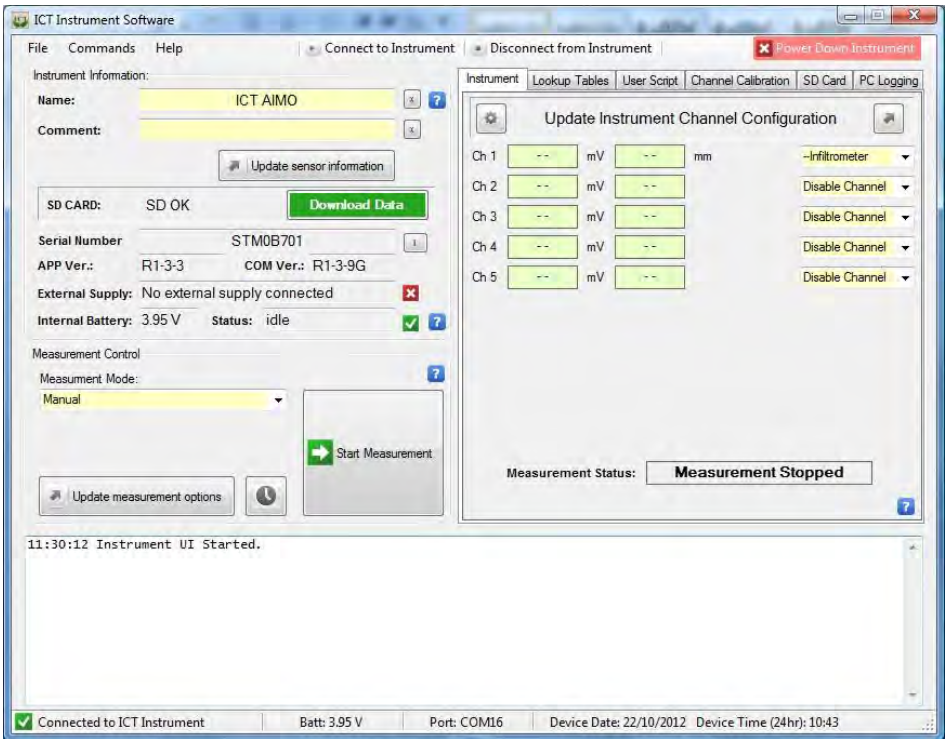
8. Set the Measurement Parameters

8.1 Software Procedure Step 1:

Position the cursor on the measurement mode drop down box and left click. A list of timing intervals will be displayed. Move the cursor over the timing interval you want between measurements and left click.

In Manual mode the HFM1 will only take a single reading each time the *"Start Measurement"* box is clicked. This is the default setting when the logger is to be powered down or set to standby mode.

8.1.2 Selecting Logging Periods from 1 Minute to 60 Minutes

If any parameter from 1 minute to 60 minutes is selected the HFM1 will record a reading at the respective time interval selected. In *"Live Mode"* the logger will continually take and record readings while ever Live Mode is selected. For measurement intervals of less than 60 seconds, see for more details.

"Measurement Mode" drop down box

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8.1.3 Software Procedure Step 2:

Left click on the *"Update Measurement Options"* box. Then click on the *"Start Measurement"* box to begin logging . Data will be recorded on the internal SD card.

To stop logging set the Measurement Mode to *"Manual"*.
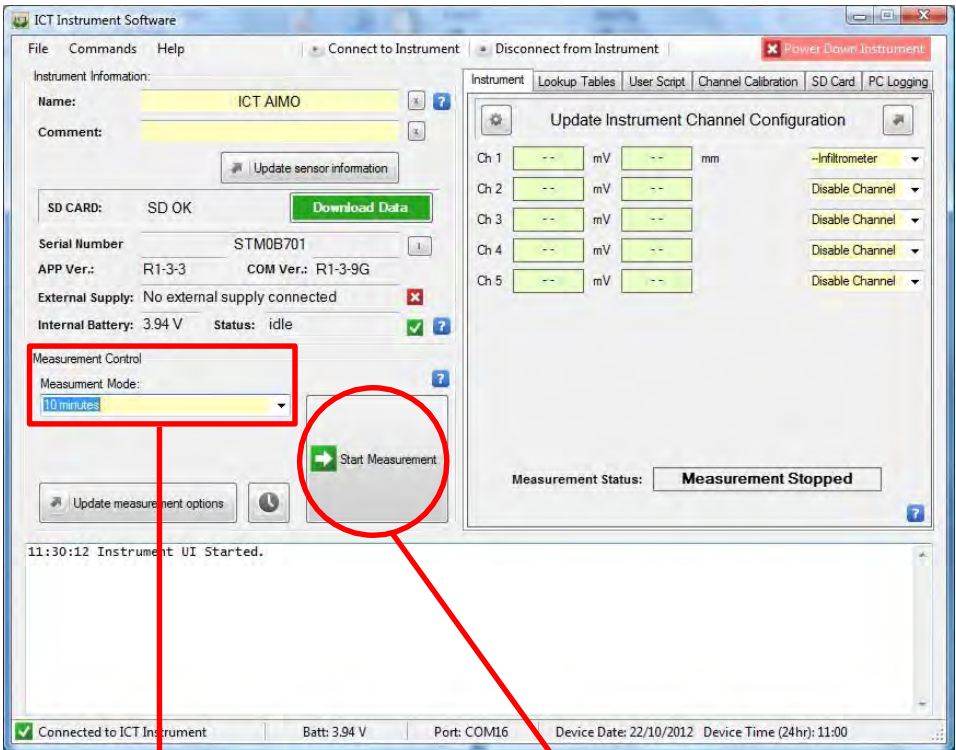
Click *"Start Measurement"* box to begin logging

To stop logging set the Measurement Mode to *"Manual"*

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8.1.4 Selecting Logging Periods of 60 Seconds or Less

The Measurement Mode drop box will allow you to select logging intervals of between 1 minute and 60 minutes or continuous conversion in Live Mode. Logging intervals of less than one minute can be set using the following procedure.
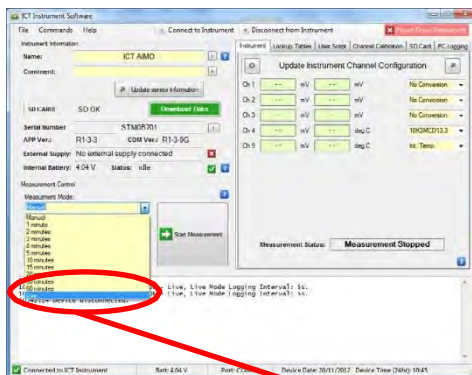
From the Measurement Mode drop down box select *"Live Mode"* then update measurement options.
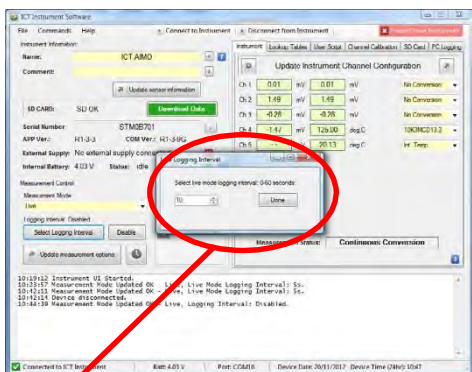
A new menu button will appear *"Select Logging Interval"*. Click on this button and the *"Live Logging Interval"* window will appear. Use the up/ down arrows in the window to select the required logging interval anywhere from 0 to 60 seconds and click done. The logger will now start collecting data at the set interval.

9. Download Data

Data can be downloaded in a number of ways. The simplest is to click the green *"Download Data"* icon on the main window under the Instrument Information section. (circle)
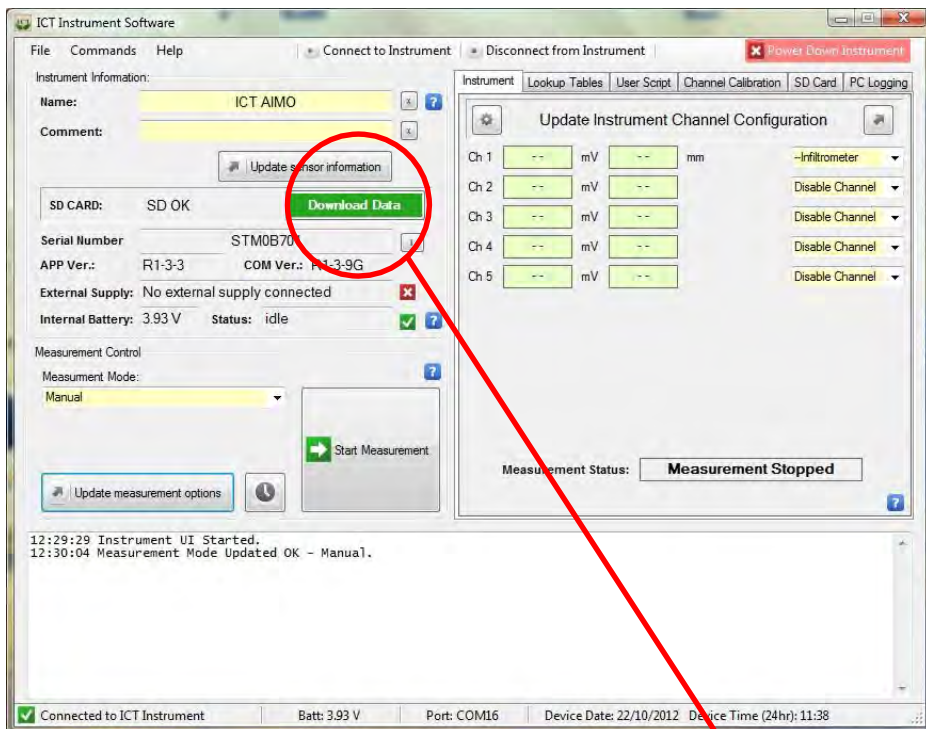
"Download Data" button

Windows will prompt you for a file name and location to store the data. The file will be stored as a .csv file and the data can be viewed in an excel spreadsheet.

When the download is complete you will be prompted to delete, rename or cancel.
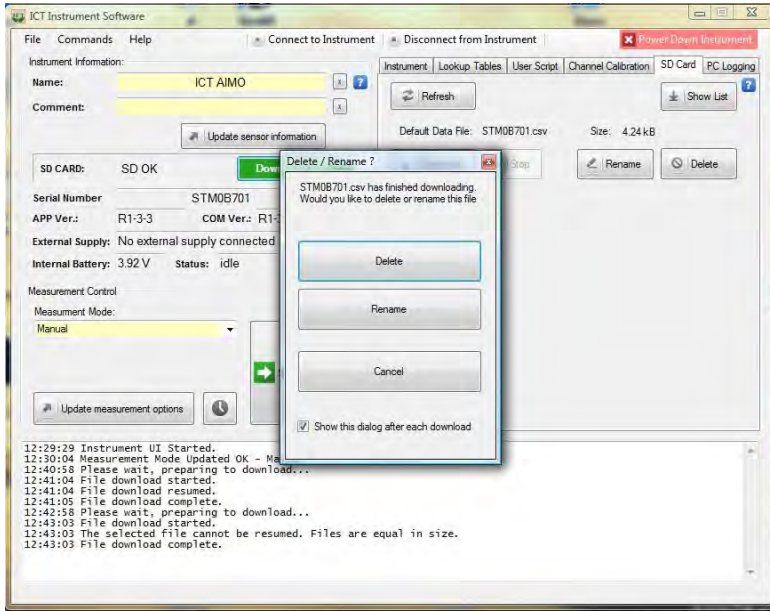
Delete will delete the csv file from the micro SD card. Note that once deleted the file cannot be retrieved. ICT only recommends this options at the end of your experiment or monitoring period when all data has been backed-up and is no longer needed on the instrument.

Rename will change the file name of the file which you have just downloaded. The renamed file will be stored on the micro SD card for later use. All new data will be downloaded to a new csv file with the default name corresponding to the serial number of your instrument.

Cancel will return you to the download screen. Your data has been downloaded and any new measured data will be appended to the end of your download file. ICT highly recommends user choose this option whenever possible. All data will be stored on a single csv file in your instrument under the serial number file name. When you download the data in the future, save the file as the same csv file name and all new data will append to the existing file.

9.1　Append File / Resume File

When attempting to download a file with the same name as an existing file, a dialogue box will appear with 2 **options:**
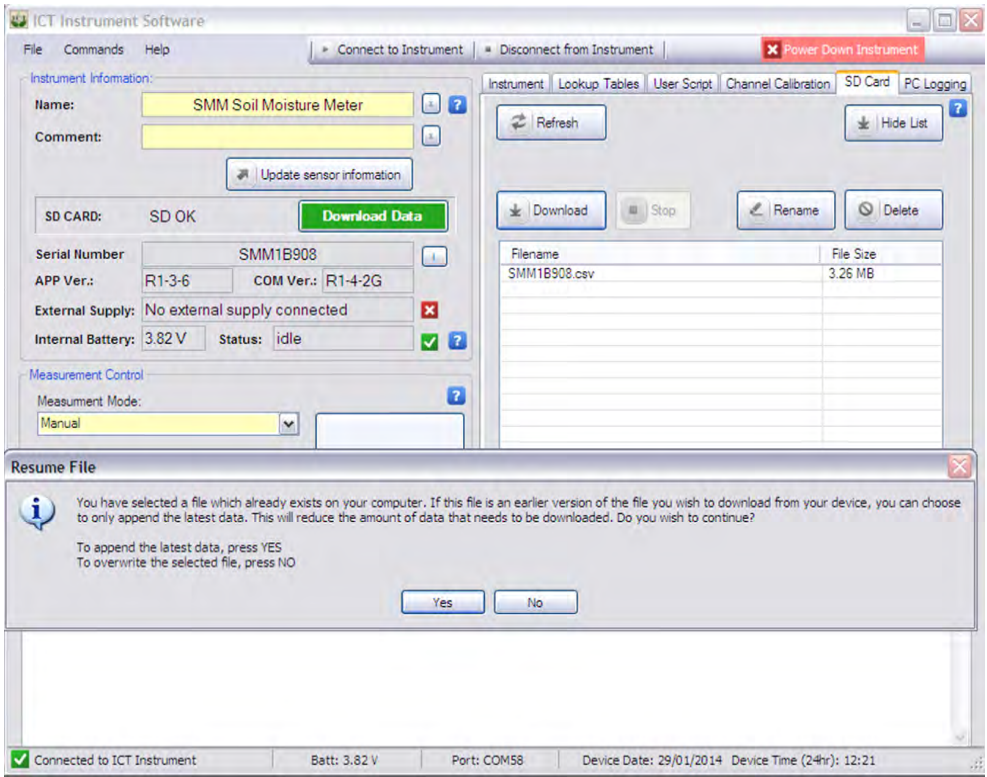
Click "YES" to append data to the existing file. This will append all new data to the existing file. This is an excellent option to choose for efficient data and file management. All your data will be stored in a single csv file which will lead to easier management later during data analysis or viewing with Sap Flow Tool Visual module.

Click "NO" and the file you will download will overwrite the existing file on your computer.

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10. Lookup Tables

Lookup Tables convert raw millivolt (mV) sensor output into meaningful measurements such as volumetric soil moisture content (%VWC), temperature, solar radiation, or oxygen concentration.

Lookup Tables need at least 2 values to be valid and then assumes there is a linear relationship between the 2 values. Typically, the sensors minimum and maximum range is entered. These values can be found on a sensor's specification sheet under a subheading such as Range.

Your ICT Instrument has already been pre-programmed with a Lookup Table or User Script. Rarely would you need to change the Lookup Table or User Script. Lookup Tables commonly used for the ICT Instrument described in this manual are found in Appendix. If you cannot find the table corresponding to your sensor please contact engineers at ICT International.

11. User Script

User Scripts allow the conversion of millivolt (mV) sensor output into meaningful measurements such as volumetric soil moisture content (%VWC), temperature, solar radiation, or oxygen concentration. User scripts are particularly useful if the relationship between the mV and the converted value is non-linear, but it can also be used for linear relationships.

Your ICT Instrument has already been pre-programmed with a Lookup Table or User Script. Rarely would you need to change the Lookup Table or User Script. User Scripts commonly used for the ICT Instrument described in this manual are found in Appendix. If you cannot find the table corresponding to your sensor please contact engineers at ICT International.

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12. Channel Calibration

Introduction

The ICT Instrument has a unique feature where individual sensors can be calibrated to a known standard. This feature is advantageous where a sensor is known to vary from the standard specifications provided by the manufacturer. Most sensors will vary from the standard specifications, the critical factor is where such variation is outside of the desired parameters for accurate test results. The ICT logger is supplied with a standard Lookup Table or User Script to suit the sensor provided with it. It is good practice to use a known standard test medium to check the calibration of the sensor before commencing a detailed field survey, to avoid errors in test results.

ICT Instrument Software

Calibration of the sensors is carried out using the ICT Instrumentation Software provided free with the ICT Data Logger. If your computer is connected to the internet the software will automatically check for any updates when you run the program. Connect your computer to the ICT Instrument using methods described in Chapter 7, "Connecting to the Instrument", and start the ICT Instrument Software.

Calibration of individual sensors is carried by calibrating the channel that the sensor is connected to. Care must be taken to ensure that the same sensor is connected to the channel where the original calibration is performed. Select the Channel Calibration tab on the logger software screen. Note that the logger must be in Manual measurement mode to enable calibration.

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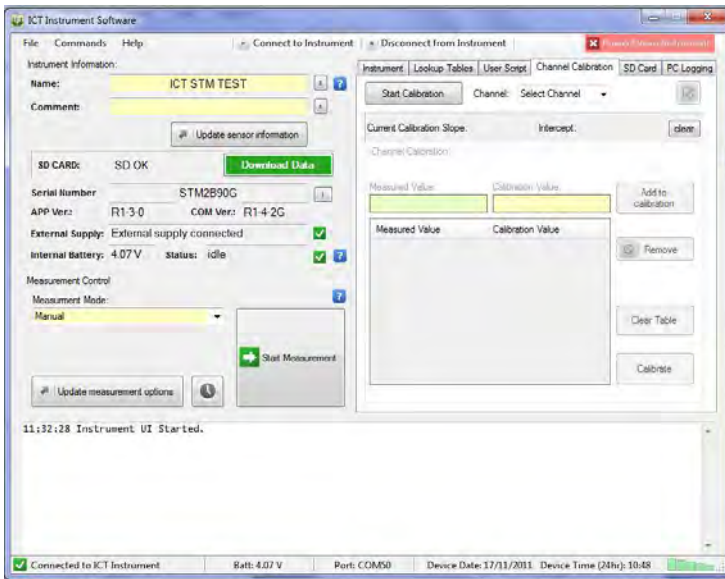
Figure 2 - Calibration Screen

Use the '**Select Channel**' drop down box to choose the required channel. The current calibration settings for that channel are displayed immediately below the selection. If no previous calibration has been performed on this channel   the values will be as shown in Figure 2, with Slope set to 1.000, and Intercept set to 0.000. Alternatively, you can remove any previous calibrations by clicking the 'Clear' button to the right of the calibration values.

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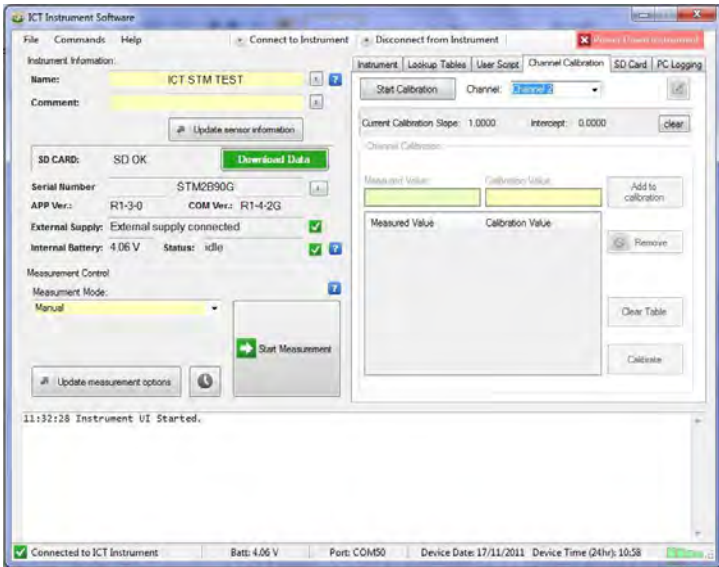
Figure 3 - Channel Selection

The next step is to click on the 'Start Calibration' button. The calibration screen will change to appear as shown in figure 3. Calibration can be done using a lookup table consisting of 3 sets of values, one of which can be a zero value entry to determine the start point of the sensor readings. The zero value is entered manually using the steps described later. The zero value entry will depend on the output values of the particular sensor to be calibrated. If you require more information on this setting contact ICT technical support. If the sensor does not use a zero value in the output ignore this step.

As stated above, the calibration process requires at least three value entries in order to develop a functioning graph of the sensor performance. In this example it is assumed that the sensor is reading 10% below correct values. The first value is straight forward, and is obtained by taking a reading from the sensor in its current state. Click on the 'Start Measurement' button to take a reading from the sensor. The value will appear in the Measured Value box as shown in figure 4. The true or corrected value is entered manually into Corrected Value box, and the '**Add to Calibration**' button is clicked to enter the values into the calibration lookup table, as shown in figure 5.

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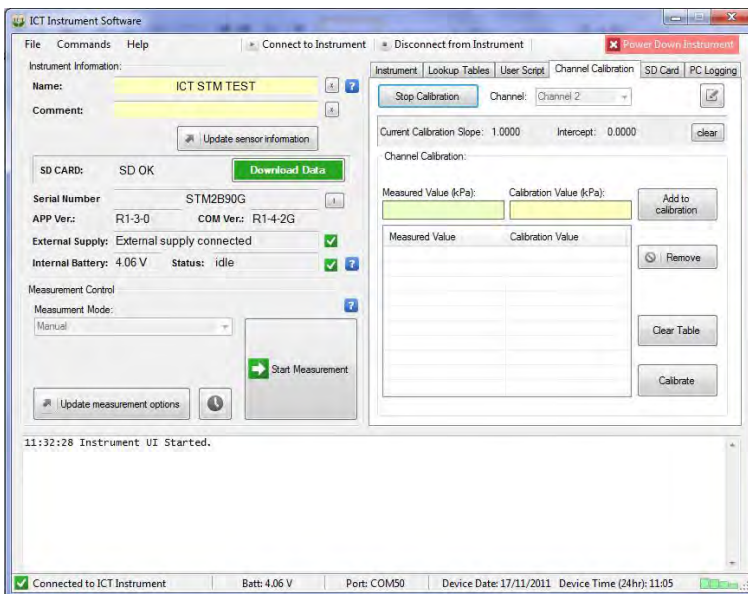
Figure 4 - Calibration Started
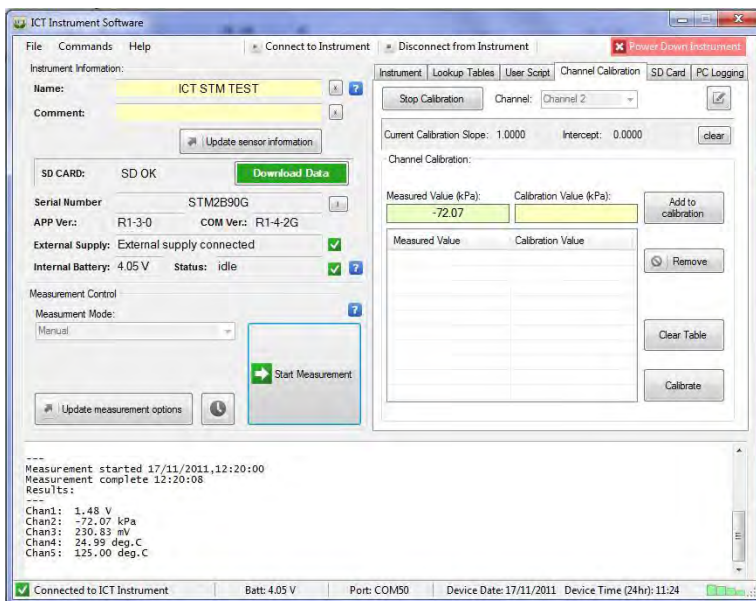
Figure 5 – Measured Value Entry

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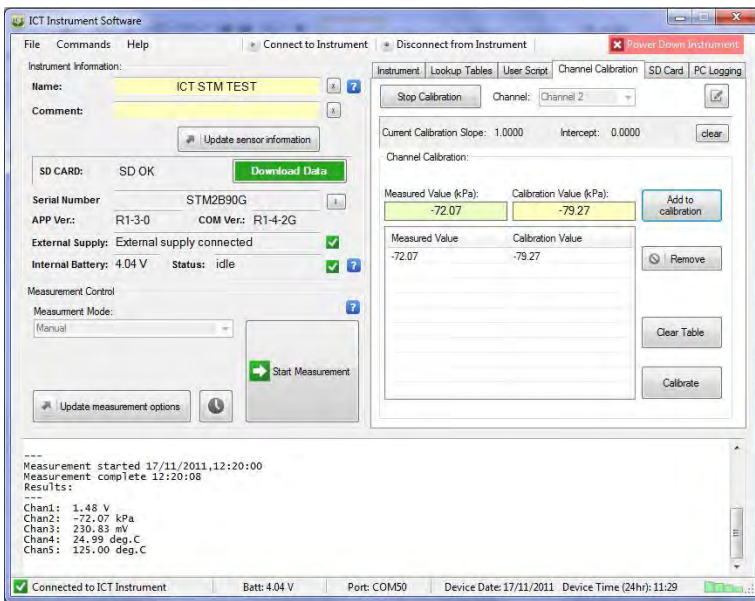
Figure 7 - Enter Corrected Value

The second and third calibration values are generated by calculation. The values for 'Measured Value' and 'Calibrated Value' are entered manually by using values within the range provided by the sensor. For example, if the expected readings for this sensor are in the range of -20kPa to -80kPa, then these values can be used to create the lookup table.

It is necessary to click on the Manual Entry pen button to enter new values. This button is located to the right of the Channel selection box, and looks like a pencil. Note that it may be necessary to click the button twice to enter the manual mode. The dialog box should appear as shown in figure 6.

You can now place the cursor in the Measured Value and Calibration Value boxes and enter a number in each box. In this example we will enter -20 in the Measured Value box, and -22 in the Calibrated Value box. This becomes the second calibration entry. After typing in the values click on the 'Add to Calibration' button to insert the values into the table. The same process is used to enter values in the range for -80 as the Measured Value, and -88 for the Calculated Value. Once again the 'Add to Calibration' button is used to add the new entries into the Calibration Table.

If you wish to you can add further entries to the calibration table. The software will create a new slope and intersection reference curve using the values you have provided. Additional values will create a more complex, and more accurate curve. However if the sensor variation is linear over the range then the 3 values will be sufficient. Note that the lowest and highest values you enter should cover the full range of readings you expect to generate from the sensor, otherwise you will obtain zero values if the measured value is outside the range of the Calibration lookup table. Should you enter incorrect values into the table, click on the particular entry and use 'Remove' button to delete that entry.
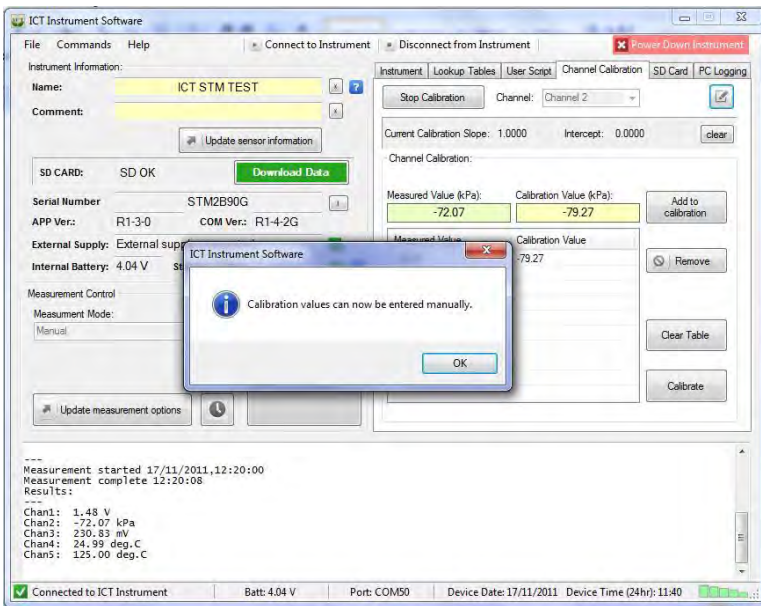
Figure 8 - Manual Entry Mode

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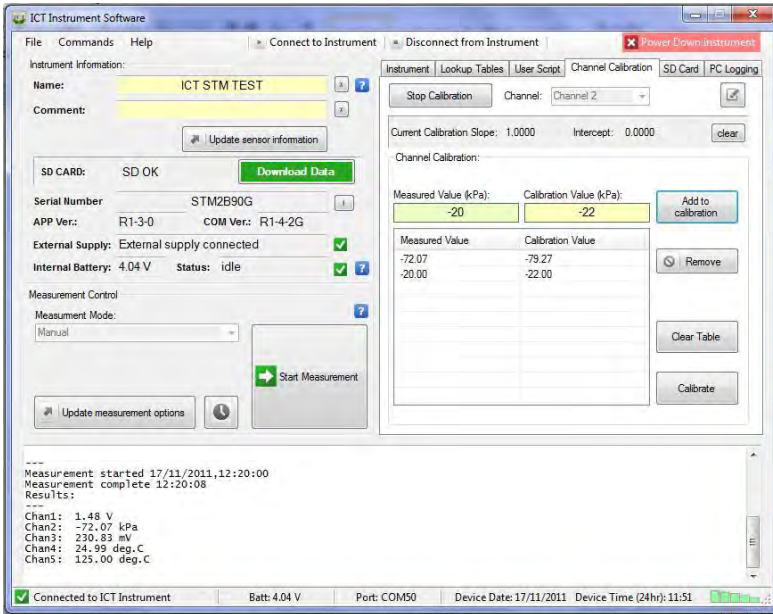
Figure 10 - New Calibration Values Entered

The calibration table is now ready to be used for the selected channel.

Click on the 'Calibrate' button to update the calibration settings. The calibration curve as shown in Figure 8 will be displayed on screen. Note the slope and intercept values, in this case representing a simple 10% change in values. If the curve is correct, click on the 'Use' button to finalise the Calibration. If the curve does not represent the desired change in values, then return to the calibration process and enter new values. A dialog box will appear asking you to confirm the calibration. To finish the process click on the 'Stop Calibration ' button, and run a Test Measurement to confirm a correct reading.
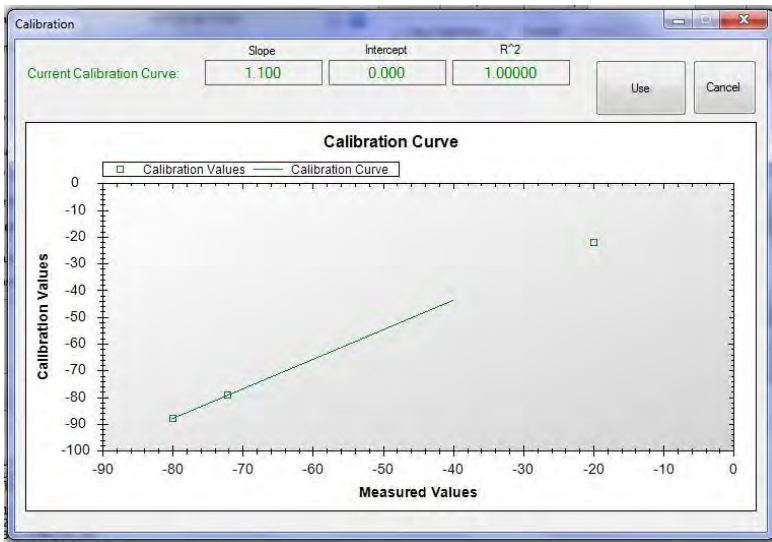
Figure 12 - Calibration Reference Curve

The selected channel is now calibrated to the sensor connected to it. If a new sensor is connected to this channel then the calibration will have to done again. Calibration of the other channels is a repeat of the same process. Note that the calibration settings are stored in the data logger, not in the software on your computer.

Once a particular channel has been calibrated the values box displaying the reading changes colour, as shown in Figure 9. The calibrated channels are shown is a darker green shading in the values box. In the figure below channel 2 is calibrated. Removing the calibration will cause the colour of the values box to revert to the lighter green shading.

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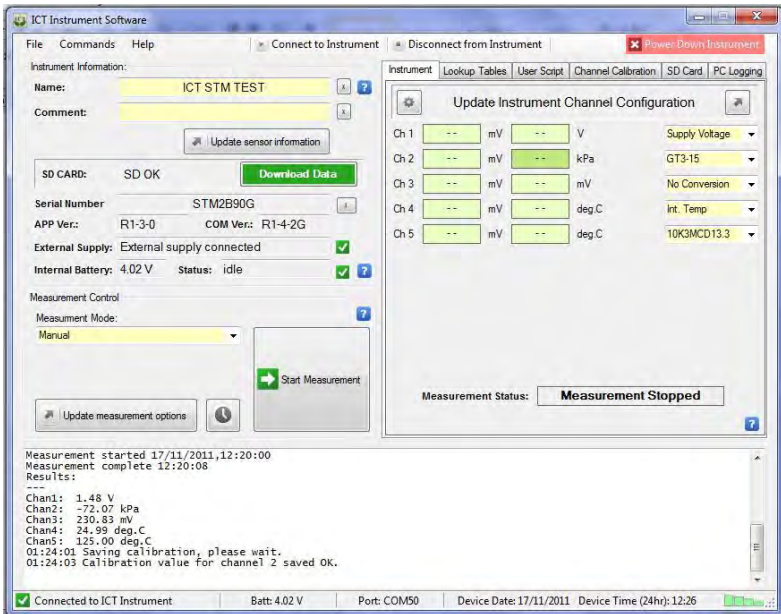
Figure 14 - Calibrated Channel

Note that the Channel Calibration can only support linear relationships between uncorrected and calibrated values. If your calibration curve is curvilinear, such as an exponential or logistic curve, then the Channel Calibration feature cannot be used. In this instance you will need to input a User Script. See Chapter 11 for more details on User Scripts.

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14. Appendicies Contents

14.1 User Scripts

14.1.1 HFP01

Wm^2
r1 = curchan / "sensitivity"
res = r1

Each HFP01 is individually calibrated at the factory and supplied with a Certificate of Calibration showing sensitivity in µV/Wm^-2.
In order for the script to convert from µV in to Wm² the text "sensitivity" on line 1 needs to be substituted with the value for sensitivity shown on the Calibration Certificate.

Example:
If the sensitivity is given as 62.2 µV/Wm^-2 the script will appear as follows:
r1 = curchan / 62.2
res= r1

14.1.2 THERM EP & THERM SS

Thermistor 3V   &   Thermistor 10V

deg C   deg C
r1 = 3220 - curchan   r1 = 10040 - curchan
r2 = 1000000 * curchan   r2 = 1000000 * curchan
r3 = r2 / r1   r3 = r2 / r1
res = lookup r3 11   res = lookup r3 11

Note: the value r1 can be checked on your ICT Instrument by testing the voltage bridge across VCC and GND on the Break-Out Board with a volt meter. The values 3220 and 10040 correspond to a volt meter measurement of 3.22V and 10.04V respectively.

14.2 Lookup Tables
14.2.1 Not relevant for this instrument

14.3 **Sensor Manuals**

14.3.1 **Introduction**

HFM1 is a measurement system for analysis of thermal resistance and thermal transmittance of building elements by in-situ measurement. It can be used for measurements according to ISO 9869 and ASTM C1155 and C1046 standards. In its standard configuration the system is equipped with two heat flux sensors as well as two pairs of matched thermocouples for differential temperature measurements.

14.3.2 **General theory of the measurement**

The in-situ measurement of thermal resistance, thermal transmittance or U-Values of buildings is often applied in studies of building elements. The thermal resistance, TR, measurement is based on simultaneous measurement of time averaged heat flux Φ (using a heat flux sensor) and differential temperature, ΔT, (two temperature sensors).

$$TR = \Delta T / \Phi \qquad\qquad\qquad (1.1)$$

The ISO and ASTM standards on the subject comment on applicability of the method, on installation and on data analysis.

The TRSYS01 consists of high accuracy electronics (measurement accuracy up to +/- 1 microvolt) as well as matched thermocouple pairs to make a differential temperature measurement with a total accuracy of better than 0.1 degrees C. HFP01 is the world"s most popular sensor for heat flux measurement through building envelopes.

The user of TRSYS01 is supposed to work according to the relevant standards, and perform his own data analysis in accordance with these standards.

The ISO and ASTM standards are:

ISO 9869: Thermal insulation – Building elements - In-situ measurement of thermal resistance and thermal transmittanc.

ASTM C 1155 – 95 (Reapproved 2001)
Standard Practice for Determining Thermal Resistance of Building Envelope Components from the In-Situ Data

ASTM C 1046 – 95 (Reapproved 2001)
Standard Practice for In-Situ Measurement of Heat Flux and Temperature on Building Envelope Components

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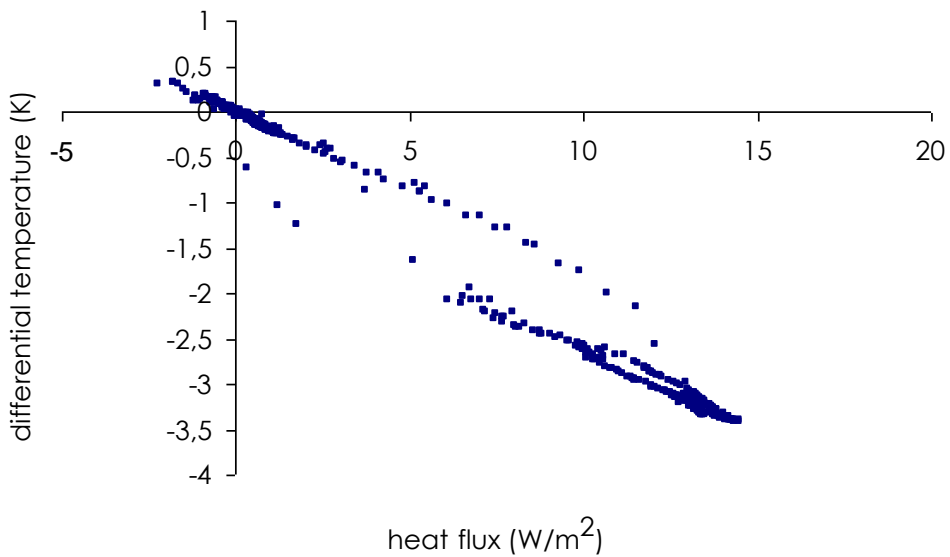
Figure 1.1 *typical graph showing obtained data during a measurement cycle of 2 days.*

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14.3.3 **Performing standard measurements**

It is now assumed that the user has installed the software and has tested the functionality of the equipment in an indoor test. The user is now supposed to be familiar with the working principles of the TRSYS01. Now it can be used in standard measurements.

Recommendations for the measurement location

It is recommended to pay attention to the following aspects of the measurement.

Location with exposure to direct solar radiation should be avoided as much as possible. In the northern hemisphere, north-facing walls are preferred.

Typically locations exposed to solar radiation are avoided, in particular when thermal resistance or H-value measurements of a building component are made.

When installing on the wall surface, in case of exposure to strong radiation (for instance direct beam solar radiation), the spectral properties of the sensor surface must be adapted to match those of the wall. This can be done by covering the sensor with paint or sheet material of the same colour.

The more heat flux, the better; strongly cooled or strongly heated rooms are ideal measurement locations. It can be considered to temporarily activate heaters or air conditioning for a perfect measurement.

The least ideal is a situation in which the heat flux is constantly changing direction. This often goes together with relatively small fluxes and strong effects of "loading"

For detailed analysis of one building element it can be beneficial to install one heat flux sensor on one side, and the other on the other side. Measuring in such a way will allow seeing the thermal response time of a system in more detail.

The location of installation preferably should be a large wall section which is relatively homogeneous. Areas with local thermal bridges should be avoided.

Whatever the exact setup, the duration of the measurement should at least be 72 hours.

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Recommendations for installation

HFP01 and thermocouples are generally installed on the surface of a wall, or alternatively integrated into the wall.

The more even the surface on which HFP01 is placed the better. The optimal configuration is the heater in the same plane as the surrounding surface of the object.

Any air gaps should be filled as much as possible.

Permanent installation is preferred. It is recommended to fix the location of the sensor by gluing with silicone glue.

Alternatively for short-term installation either toothpaste (1-2 days) or "DOW CORNING heat sink compound 340" can be used. Typically temporary installation is fixed using tape across the guard. The tape should be as far as possible to the edge.

Independent attachment of the cable can be done to an object that can resist strain in case of accidental force.

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List of symbols

Heat flux	φ	$W\,m^{-2}$
Thermal conductivity of the surrounding medium or object on which the sensor is mounted	λ	W/mK
Voltage output	V	V
HFP01 sensitivity	E_{sen}	$\mu V/Wm^{-2}$
Thermal conductivity dependence of E_{sen}	E_{λ}	mK/W
Time	t	s
Surface area	A	m^2
Electrical resistance	R_e	Ω
Thermal resistance	R_{th}	Km^2/W
Temperature	T	K
Temperature dependence	TD	$\%/K$
Depth of burial	d	m

Subscripts

Property of the sensor	sen
Property of air	air
Property during calibration	cal
Property of the object on which HFP01 is mounted	obj
Property at the soil surface	surf

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Introduction and General Theory

HFP01 is the world's most popular sensor for heat flux measurement in the soil and through walls and building envelopes. By using a ceramics-plastic composite body the total thermal resistance is kept small.

HFP01 serves to measure the heat that flows through the object in which it is incorporated or on which it is mounted. The actual sensor in HFP01 is a thermopile. This thermopile measures the differential temperature across the ceramics-plastic composite body of HFP01. Working completely passive, HFP01 generates a small output voltage proportional to the local heat flux.

Using HFP01 is easy. For readout one only needs an accurate voltmeter that works in the millivolt range. To calculate the heat flux, the voltage must be divided by the sensitivity; a constant that is supplied with each individual instrument.

HFP01 can be used for in-situ measurement of building envelope thermal resistance (R-value) and thermal transmittance (H-value) according to ISO 9869, ASTM C1046 and ASTM 1155 standards.

Traceability of calibration is to the "guarded hot plate" of National Physical Laboratory (NPL) of the UK, according to ISO 8302 and ASTM C177.

A typical measurement location is equipped with 2 sensors for good spatial averaging. If necessary two sensors can be put in series, creating a single output signal.

If measuring in soil, in case a more accurate measurement is needed the model HFP01SC should be considered.

In case a more sensitive measurement is required, model HFP03 should be considered.

In case of special requirements, like high temperature limits, smaller size or flexibility the PU series could offer a solution.

This manual can also be used for HFP03. Differences between HFP03 and HFP01 are highlighted in a special appendix on HFP03.
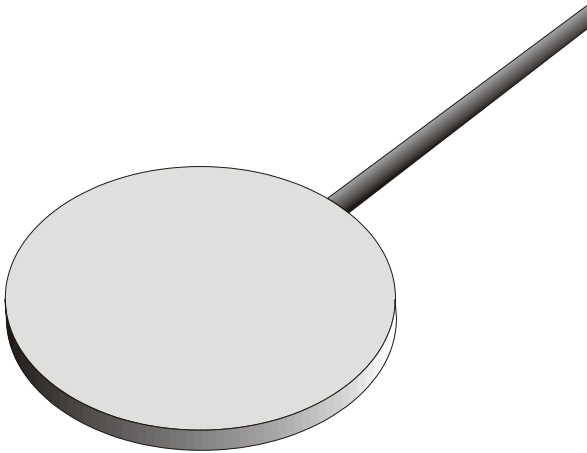
Figure 1 *Drawing of HFP01 sensor*
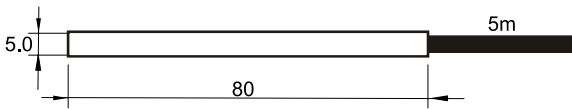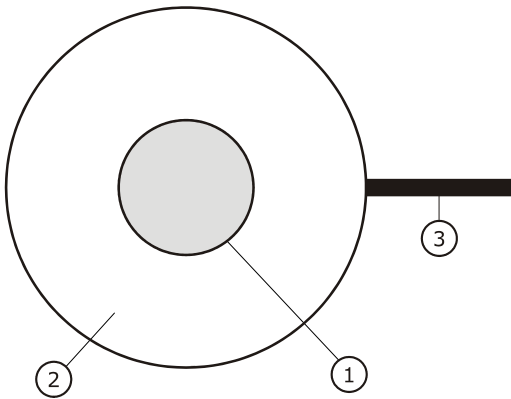
Figure 2 *HFP01 heat flux plate dimensions:*
(1) sensor area, (2) guard of ceramics-plastic composite,
(3) cable, standard length is 5 m. All dimensions are in mm.

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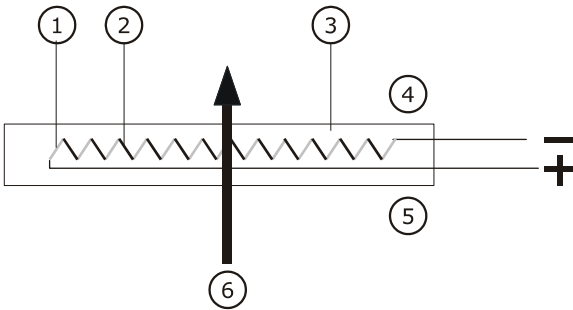
Figure 1.1 General characteristics of a heat flux sensor like HFP01.
When heat (6) is flowing through the sensor, the filling material (3) will act as a thermal resistance. Consequently the heat flow φ will go together with a temperature gradient across the sensor, creating a hot side (5) and a cold side (4). The majority of heat flux sensors is based on a thermopile; a number of thermocouples (1,2) connected in series.

A single thermocouple will generate an output voltage that is proportional to the temperature difference between the joints (copper-constantan and constantan-copper). This temperature difference is, provided that errors are avoided, proportional to the heat flux, depending only on the thickness and the average thermal conductivity of the sensor.

Using more thermocouples in series will enhance the output signal. In the picture the joints of a copper-constantan thermopile are alternatively placed on the hot- and the cold side of the sensor. The two different alloys are represented in different colours 1 and 2. The thermopile is embedded in a filling material, usually a plastic, in case of HFP01 a special Ceramics-plastic composite. Each individual sensor will have its own sensitivity, E_{sen}, usually expressed in Volts output, V_{sen}, per Watt per square meter heat flux φ. The flux is calculated:. $φ = V_{sen} / E_{sen}$.

The sensitivity is determined at the manufacturer, and is found on the calibration certificate that is supplied with each sensor.

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1.2 Detailed description of the measurement:
resistance error, contact resistance, deflection error and temperature dependence

As a first approximation, the heat flux is expressed as: $\varphi = V_{sen} / E_{sen}$

1.2.1

This paragraph offers a more detailed description of the heat flux measurement. It should be noted that the following theory for correcting deflection errors and temperature dependence is not often applied. Usually one will work with formula 1.2.1, possibly corrected with 1.2.2.

When mounting the sensor in or on an object with limited thermal resistance, the sensor thermal resistance itself might be significantly influencing the undisturbed heat flux. One part of the resulting error is called the resistance error, reflecting a change of the total thermal resistance of the object.
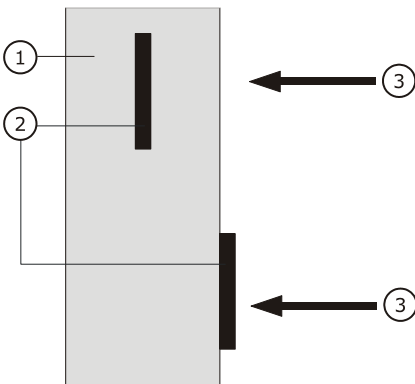
Figure 1.2.1 *The resistance error: a heat flux sensor (2) increases or decreases the total thermal resistance of the object on which it is mounted (1) or in which it is incorporated. This can lead either to a larger of smaller (increase of or decrease of the-) heat flux (3).*
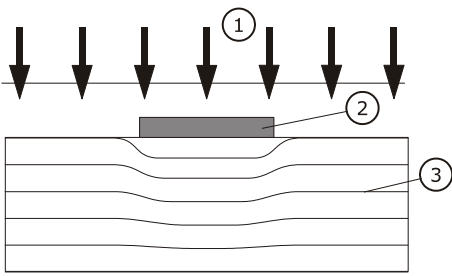
Figure 1.2.2 *The resistance error: a heat flux sensor (2) increases or decreases the total thermal resistance of the object on which it is mounted or in which it is incorporated. An otherwise uniform flux (1) is locally disturbed (3). In this case the measured heat flux is smaller than the actual undisturbed flux,(1).*

A first order correction of the measurement is:

$$\varphi = (R_{thobj} + R_{thsen}) \, V_{sen} / E_{sen} \, R_{thobj} \qquad\qquad 1.2.2$$

This correction is often applied with thin or well-isolated walls. Note: this correction can only be determined for objects with limited (finite) dimensions. For this reason this correction is not applicable in soils.

In addition to the resistance error, the fact that the thermal conductivity of the surrounding medium differs from the sensor thermal conductivity causes the heat flux to deflect. The resulting error is called the deflection error. The deflection error is determined in media of different thermal conductivity by experiments or using theoretical approximations. The result of these experiments is laid down as the so-called thermal conductivity dependence E_λ. The order of magnitude of E_λ is constant for one sensor type. For HFP01, E_λ is given in the list of specifications.

$$E_{sen} = E_{sen, \, cal} \, (1 + E_\lambda \, (\lambda_{cal} - \lambda_{med})) \qquad\qquad 1.2.3$$

Note: this correction can only be applied when there is a substantial amount of (at least 40 mm) medium on both sides of the sensor. In soils λ_{med} usually is not known. The value of λ_{cal} typically is zero.

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2   Application in meteorology

In meteorological applications the primary purpose is to measure
the part of the energy balance that goes into the soil. This soil
heat flux in itself is in most cases of limited interest. However,
knowing this quantity, it is possible to "close the balance". In other words
,apply the law of conservation of energy to check the quality of the other
(convective and evaporative) flux measurements. For more information
on meteorological measurement of heat flux, see the appendix.

Users should be aware of the fact that the soil heat flux
measurement with HFP01 in most cases is not resulting in a high
accuracy result. The main causes are:
1 the fact that measurement at one location in the soil will have
only limited validity for a larger area; variability of soil surface
can be very lage.
2 the fact that variations in soil thermal properties over time
result in significant measurement errors.

If measuring in soil, in case a more accurate measurement is
needed the model HFP01SC should be considered.
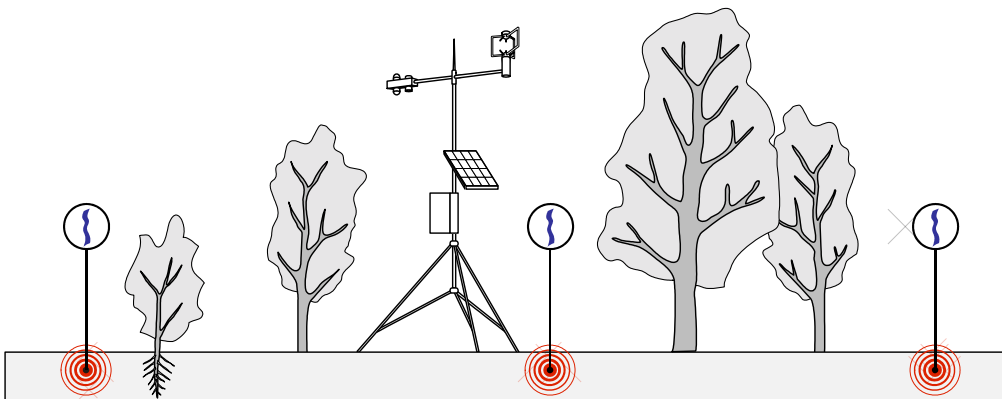
Figure 2.1 *Typical meteorological energy balance measurement
system with HFP01 installed under the soil.*

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In a perfect environment, the initial calibration accuracy of heat flux sensors is estimated to be +3 /- 3%.

In field experiments it is difficult to find one location that can be considered to be representative of the whole region. Also temporal effects of shading on the soil surface can give a false impression of the heat flux. For this reason typically two sensors are used for each station, usually at a distance of 5 meters.

Apart from the question of representativeness of the measurement location, the main problem with heat flux measurements in meteorology is that the sensitivity of a heat flux sensor is dependent on the thermal conductivity of the surrounding medium. This deflection error is described in chapter

1. In soil heat flux measurement the accuracy of soil heat flux measurements very much suffers from the fact that the surrounding medium is both unknown to the manufacturer and changing over time. A typical HFP01 has a thermal conductivity of 0.8 W/mK, while soils can vary between extremes of 0.2 and 4 W/mK. Sand in relatively dry condition can have a thermal conductivity of 0.3 W/mK (perfectly dry 0.2) while the same sand when saturated with water reaches 2.5 W/mK. A typical HFP01 performing a correct measurement in dry sand will make a – 16% error in wet sand. As in wet sand the heat tends to travel around the badly conducting sensor, the flux will be underestimated by 16%.
This example serves to illustrate that in soils where conditions vary the so-called thermal conductivity dependence leads to large deflection errors.

The third important error is temperature dependence.
Over the entire temperature range from -30 to + 70 degrees C, the temperature error is +/- 5%. Taking the worst case soil, pure sand, for the conventional heat flux measurement in meteorology the overall worst case accuracy is estimated to be +8 /- 24%. This is rounded off to +10 / -25 %.

In most situations the soil will not be pure sand, and in an average climate the difference between the yearly extremes might be -10 + 40 degrees C and a thermal conductivity range from 0.2 to 1 W/mK. The temperature error then is +2 / -3%, the thermal conductivity accounts for +0 / - 7%, the calibration +3 / -3 %. The result of +5 / -13 % is rounded off to +5 / -15%

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Heat flux sensors in meteorological applications are typically buried at a depth of about 5 cm below the soil surface. Burial at a depth of less than 5 cm is generally not recommended. In most cases a 5 cm soil layer on top of the sensor offers just sufficient mechanical consistency to guarantee long-term stable installation conditions.
Burial at a depth of more than 8 cm is generally not recommended, because time delay and amplitude become less easily traceable to surface fluxes at larger installation depths. See the appendix for more details.

Summary:

In case of use of HFP01 in meteorological applications, the use of 2 sensors per station is recommended. This creates redundancy and a better possiblity for judging the quality of the measurement accuracy. Typically one will work with two separately measured sensor outputs; the average value is the measurement result.
In normal soils (clays, silts) the overall expected measurement accuracy for 12 hr totals is +5 / -15%.
In case of pure sands the overall measurement accuracy for 12 hr totals is +10 / -25 %.
The accuracy mainly is a function of the thermal conductivity of the surrounding medium. In case of soils the moisture content plays a dominant role.
The wider accuracy range in sand is due to the fact that the thermal conductivity of sand varies with moisture content from roughly 0.2 (perfectly dry) to 2.5 (saturated).
With other soils and walls (see chapter on building physics) the variation of thermal conductivity is much less; roughly from 0.1 to 1 W/mK.
If measuring in soil, in case a more accurate measurement is needed the model HFP01SC should be considered.

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3 Application in building physics

HFP01 can be used for in-situ measurement of building envelope thermal resistance (R-value) and thermal transmittance (H-value) according to ISO 9869, ASTM C1046 and ASTM 1155 standards.

When studying the energy balance of buildings, heat is exchanged by various mechanisms. The total result is a certain heat flux. The dominant mechanisms are usually radiative transfer by solar radiation and convective transport by flowing air.

In most applications in building physics the sensor HFP01 is simply mounted on or in the object of interest (see figure 3.1). At the sensor surface, the convective heat of the air and the radiation by the sun are transformed into conductive heat. In case of incorporation into the wall, the conductive flux through the wall is directly measured.
If direct beam solar radiation is present, the solar radiation is usually dominant. The maximum expected solar radiation level is about 1500 W/m^2. In case of convective transport of heat by the air, the convective transport is roughly proportional to the difference in temperature between wall and air, and strongly depends on the local wind speed. See the appendix on heat transfer in building physics for more information.

It is possible that the heat flux sensor contributes significantly to the total thermal resistance of the object (resistance error). In this case the heat flux measurement must be corrected. For the correction, see chapter 1. In order to limit the resistance error, in all cases the contact between sensor and surrounding material should be as well and as stable as possible, so that air gaps are not influencing the measurement.

In a perfect environment, the initial calibration accuracy of heat flux sensors is estimated to be +3 /- 3%.
In case of use of HFP01 on walls (insulating as well as bricks and cements) the overall expected measurement accuracy for 12 hr totals is +5 / -5 %.

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In case of analysis of thermal resistance of building envelopes, the minimum recommended measurement time is 48 hours.

Hukseflux also offeres a complete measurement system for analysis of building envelopes: TRSYS.
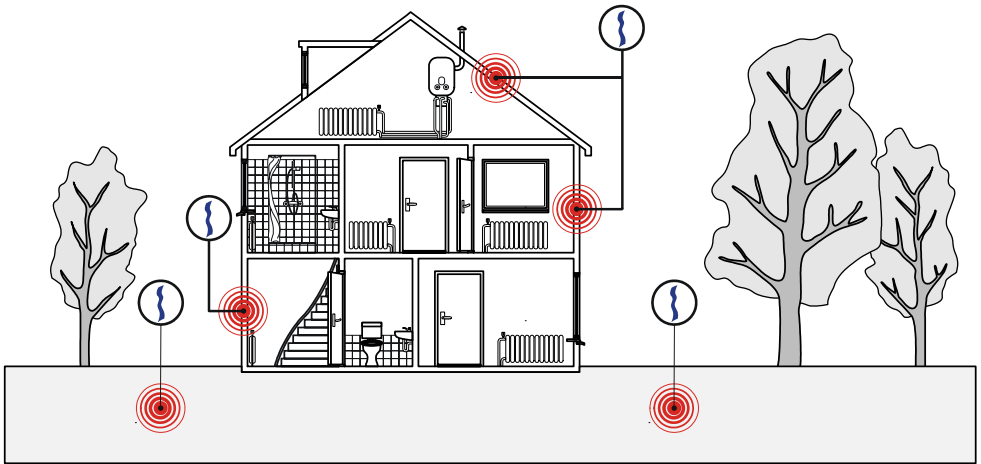
Figure 3.1 *Estimation of convective, radiative and conductive heat flux in building physics. The heat flux sensor is simply mounted on or in the object of interest. This is typically in walls, but can also be in the soil, e.g. on top of an underground heat storage tank.*

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4   Specifications of HFP01

HFP01 is a heat flux sensor that measures the local heat flux perpendicular to the sensor surface in the medium in which it is incorporated or the object on which it is mounted. It can only be used in combination with a suitable measurement and control system. The HFP01 specifications except size, resistance, sensitivity and weight are also applicable to sensor type HFP03; see appendix.

HFP01 GENERAL SPECIFICATIONS	
Specified measurements	Heat flux in W/m^2 perpendicular to the sensor surface
Installation	See the product manual for recommendations.
Temperature range	-30 to +70 degrees C
Recommended number of sensors	Meteorological: two for each measurement station. Building Physics: typically 1 or 2 sensors per measurement location depending on building and wall properties.
CE requirements	HFP01 complies with CE directives
Series connection	HFP01 sensors can be put electrically in series to create a sensor with higher sensitivity of better spatial resolution using only one single readout channel. The sensitivity then is the average of the two sensitivities.
Thermal conductivity dependence E_λ	-0.07 % m.K/W (nominal value) $\lambda_{cal} = 0$
Temperature dependence TD	< +0.1%/ °C

Table 4.1 *List of HFP01 specifications. (continued on next 2 pages)*

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HFP01 MEASUREMENT SPECIFICATIONS	
Initial calibration accuracy	+3 /- 3%
Overall uncertainty statement according to ISO	estimated to be within +5 /- 5%, based on a standard uncertainty multiplied by a coverage factor of k = 2, providing a level of confidence of 95%. Application related errors should be added to this error.
Expected typical accuracy (12 hr totals) of heat flux measurement in soil	Initial calibration accuracy: +3 /- 3% Added errors within most common soils, (clays, silts, organic), on most walls @ 20 degrees C: +0 / - 7% Added typical temperature error: -10 + 40 degrees C +2 / - 3% Total typical value in soil (rounded off): within +5 / -15 %
Expected worst case accuracy (12 hr totals) of heat flux measurement in soil	Initial calibration accuracy: +3 /- 3% Added errors with worst case soil, pure sand @ 20 degrees C: +0 / - 16% Added worst case temperature error: -30 + 70 degrees C +5 / - 5% Total worst case value in soil (rounded off): within +10 / -25 %
Expected typical accuracy (12 hr totals) of heat flux measurement on a wall	Initial calibration accuracy: +3 /- 3% Added typical temperature error: -10 + 40 degrees C +2 / - 3% Total typical value on a wall (insulating, brick, cement) (rounded off): within +5 / -5 % Low thermal resistance walls require correction for the resistance error.

Table 4.1 *List of HFP01 specifications. (started on previous page, continued on next page)*

HFP01 SENSOR SPECIFICATIONS	
E$_{sen}$ (nominal)	50 µV/ W. m^{-2} (exact value on calibration certificate) $\lambda_{cal} = 0$, T$_{cal}$ =20 °C
Sensor thermal conductivity	0.8 W/mK
Sensor thermal resistance R$_{th}$	< 6.25 10^{-3} Km^2/W
Response time (nominal)	± 3 min (equals average soil)
Range	+ 2000 to - 2000 W.m^{-2}
Non stability	< 1% change per year (normal meteorological / building physics use)
Required readout	1 differential voltage channel or possibly (less ideal) 1 single ended voltage channel. When using more than one sensor and having a lack of input channels, it can be considered to put several sensors in series, while working with the average sensitivity.
Expected voltage output	Meteorology: -10 to - + 20 mV Building physics: -10 to 75 mV (exposed to solar radiation)
Power required	Zero (passive sensor)
Resistance	2 Ohm (nominal) plus cable resistance
Required programming	$\varphi = V_{sen}/ E_{sen}$
Sensor dimensions	80 mm diameter, 5 mm thickness
Cable length, diameter	5 meters, 5 mm
Weight including 5 m cable, transport dim.	0.2 kg transport dimensions 32x23x3 cm
CALIBRATION	
Calibration traceability	to the "guarded hot plate" of National Physical Laboratory (NPL) of the UK. Applicable standards are ISO 8302 and ASTM C177.
Recalibration interval	Dependent on application, if possible every 2 years, see appendix
OPTIONS	
Extended cable	Additional cable length x metres (add to 5m), AC100 amplifier, LI 18 hand held readout, extended temperature range

Table 4.1 *List of HFP01 specifications. (started on previous 2 pages)*

5 Short user guide

Preferably one should read the introduction and first chapters to get familiarised with the heat flux measurement and the related error sources.

The sensor should be installed following the directions of the next paragraphs. Essentially this requires a data logger and control system capable of readout of voltages, and capability to perform division of the measurement by the sensitivity.

The first step that is described in paragraph 6 is and indoor test. The purpose of this test is to see if the sensor works.

The second step is to make a final system set-up. This is strongly application dependent, but it usually involves permanent installation of the sensor and connection to the measurement system.
Directions for this can be found in paragraphs 7 to 11.

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6   Putting HFP01 into operation

It is recommended to test the sensor functionality by checking the impedance of the sensor, and by checking if the sensor works, according to the following table: (estimated time needed: 5 minutes)

Warning: during this part of the test, please put the sensor in a thermally quiet surrounding because a sensor that generates a significant signal will disturb the measurement. Check the impedance of the sensor. Use a multimeter at the 10 ohms range. Measure at the sensor output first with one polarity, than reverse polarity. Take the average value.	The typical impedance of the wiring is 0.1 ohm/m. Typical impedance should be 1.5 ohm for the total resistance of two wires (back and forth) of each 5 meters, plus the typical sensor impedance of 2 ohms. Infinite indicates a broken circuit; zero indicates a short circuit.
Check if the sensor reacts to heat flux. Use a multimeter at the millivolt range. Measure at the sensor output. Generate a signal by touching the thermopile hot joints (red side) with your hand.	The thermopile should react by generating a millivolt output signal.

Table 6.1 *Checking the functionality of the sensor. The procedure offers a simple test to get a better feeling how HFP01 works, and a check if the sensor is OK.*

The programming of data loggers is the responsibility of the user. Please contact the supplier to see if directions for use with your system are available.

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7   Installation of HFP01 in meteorology

HFP01 is generally installed at the location where one wants to measure at least 4 cm depth below the surface. A typical depth of installation is 5 cm.

Typically 2 sensors are used per measurement location in order to promote spatial averaging, and to have some redundancy for improved quality assurance. Sensors are typically several meters apart.
The more even the surface on which HFP01 is placed the better. When covering HFP01 with soil, it should be done such that the soil below and on top is the same. If possible, it is safest to install HFP01 from the side. Care should be taken to prevent the creation of air gaps between sensor and soil.
In meteorological applications, permanent installation is preferred. It is recommended to fix the location of the sensor by attaching a metal pin to the cable. Attachment of the pin to the cable can be done using a tie-wrap.
HFP01 sensors can be put electrically in series to create a sensor with higher sensitivity of better spatial resolution using only one single readout channel. Sensitivity is the average of the two sensitivities.

Table 7.1 *General recommendations for installation of HFP01. In case of exceptional applications, please contact Hukseflux.*

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8   Installation of HFP01 in building physics

HFP01 is generally installed on the surface of a wall, or alternatively it is integrated into the wall.

Typically 2 sensors are used per measurement location in order to promote spatial averaging, and to have some redundancy for improved quality assurance. Sensors are typically several meters apart.
Location with exposure to direct solar radiation should be avoided as much as possible. In the northern hemisphere, north-facing walls are preferred.
Typically locations exposed to solar radiation are avoided, in particular when thermal resistance or H-value measurements of a building component are made.
When installing on the wall surface, in case of exposure to strong radiation (for instance direct beam solar radiation), the spectral properties of the sensor surface must be adapted to match those of the wall. This can be done by covering the sensor with paint or sheet material of the same colour.
The more heat flux, the better; strongly cooled or strongly heated rooms are ideal measurement locations. It can be considered to temporarily activate heaters or air conditioning for a perfect measurement.
The least ideal is a situation in which the heat flux is constantly changing direction. This often goes together with relatively small fluxes and strong effects of "loading"
For detailed analysis of one building element it can be beneficial to install one heat flux sensor on one side, and the other on the other side. Measuring in such a way will allow seeing the thermal response time of a system in more detail.
The location of installation preferably should be a large wall section which is relatively homogeneous. Areas with local thermal bridges should be avoided.
The more even the surface on which HFP01 is placed the better. The optimal configuration is the heater in the same plane as the surrounding surface of the object.

Table 8.1 *General recommendations for installation of HFP01 in application in building physics. In case of exceptional applications, please contact Hukseflux. (continued on next page)*

Any air gaps should be filled as much as possible.
Permanent installation is preferred. It is recommended to fix the location of the sensor by gluing with silicone glue. Alternatively for short-term installation either toothpaste (1-2 days) or "DOW CORNING heat sink compound 340" can be used. Typically temporary installation is fixed using tape across the guard. The tape should be as far as possible to the edge. Independent attachment of the cable can be done to an object that can resist strain in case of accidental force.
HFP01 sensors can be put electrically in series to create a sensor with higher sensitivity of better spatial resolution using only one single readout channel.

Table 8.1 *General recommendations for installation of HFP01 in application in building physics. In case of exceptional applications, please contact Hukseflux. (started previous page)*

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9   Maintenance of HFP01

Once installed, HFP01 is essentially maintenance free. Usually errors in functionality will appear as unreasonably large or small measured values.

In case 2 sensors are mounted on one location the ratio of measurement resuls could be monitored over time; this will give a clue if there is any unstability. Typicaly long term comparison of 2 sensors can serve as an alternative for re-calibration at the factory.

As a general rule, this means that a critical review of the measured data is the best form of maintenance.
At regular intervals the quality of the cables can be checked.

Theoretically, it is a possibiliy to send sensors back to the factory for re-caliration; The reality os that in mist applications this is not possible. Recalibration of HFP01 often is not possible, in particular if sensors are dug in or permanently glued to a surface. If the intercomparison between 2 sensor on one location is judged to be insufficient, use of model HFP01SC self-calibrating heat flux sensor could be considered.

In case of use in building physics, re-calibration can be done in the field by monting a second "reference" HFP01 on top of the "field" sensor, and by measuring the ratio of the outputs over a longer time. By measuring 10 minute averages, one can create a correlation.

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Requirements for data acquisition / amplification

Capability to measure microvolt signals	Preferably: 5 microvolt accuracy Minimum requirement: 50 microvolt accuracy (both across the entire expected temperature range of the acquisition / amplification equipment) In case of low amplifier accuracy it should be considered either to put two sensors in series, to purchase a pre-amplifier or to use model HFP03.
Capability for the data logger or the software	To store data, and to perform division by the sensitivity to calculate the heat flux.

Table 9.1 *Requirements for data acquisition and amplification equipment.*

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10 Electrical connection of HFP01

In order to operate, HFP01 should be connected to a measurement and system as described above. A typical connection is shown in table 11.1.
HFP01 is a passive sensor that does not need any power. Cables generally act as a source of distortion, by picking up capacitive noise. It is a general recommendation to keep the distance between data logger or amplifier and sensor as short as possible. For cable extension, see the appendix on this subject.

Wireire	Co	Measurement system
Sensor output +	White	Voltage input +
Sensor output -	Green	Voltage input – or (Analogue) ground
Shield		(Analogue) ground or Voltage input -

Table 10.1 *The electrical connection of HFP01. The heat flux plate output usually is connected to a differential voltage input.*

Wireire	Co	Measurement system
Sensor 1 output +	White	To sensor 2 output -
Sensor 1 output -	Green	Voltage input – or (Analogue) ground
Sensor 2 output +	White	Voltage input +
Sensor 2 output -	Green	To sensor 1 output +
Shield		(Analogue) ground or Voltage input -

Table 10.2 *The electrical connection of two sensors HFP01 in series. When using more than one sensor and having a lack of input channels, it can be considered to put several sensors in series, while working with the average sensitivity.*

11 Appendices

11.1 Appendix on cable extension for HFP01

HFP01 is equipped with one cable. It is a general recommendation to keep the distance between data logger or amplifier and sensor as short as possible. Cables generally act as a source of distortion, by picking up capacitive noise. HFP01 cable can however be extended without any problem to 100 meters. If done properly, the sensor signal, although small, will not significantly degrade because the sensor impedance is very low.
Cable and connection specifications are summarised below.

Cable	2-wire shielded, copper core (at Hukseflux we use 3 wire shielded, of which we only use 2 per cable)
Core resistance	0.1 Ω/m or lower
Outer diameter	(preferred) 5 mm
Outer sheet	(preferred) polyurethane (for good stability in outdoor applications).
Connection	Either solder the new cable core and shield to the original sensor cable, and make a waterproof connection using cable shrink, or use gold plated waterproof connectors. Preferably the shield should also be extended.

Table 11.1.1 *Specifications for cable extension of HFP01.*

11.2 Appendix on trouble shooting

This paragraph contains information that can be used to make a diagnosis whenever the sensor does not function.

The sensor does not give any signal	1 Measure the impedance across the sensor wires. This check can be done even when the sensor is buried. The resistance should be around 2 ohms (sensor resistance) plus cable resistance (typically 0.1 ohm/m). If it is closer to zero there is a short circuit (check the wiring). If it is infinite, there is a broken contact (check the wiring). 2 Check if the sensor reacts to an enforced heat flux. In order enforce a flux, it is suggested to mount the sensor on a piece of metal, create a thermal connection with some thermal paste, that is used in electronics (if not available toothpaste will also do), and to use a lamp as a thermal source. A 100 Watt lamp mounted at 10 cm distance should give a definite reaction. 3 Check the data acquisition by applying a mV source to it in the 1 mV range.
The sensor signal is un-realistically high or low.	1 Check if the right calibration factor is entered into the algorithm. Please note that each sensor has its own individual calibration factor. 2 Check if the voltage reading is divided by the calibration factor by review of the algorithm. 3 Check if the mounting of the sensor still is in good order. 4 Check the condition of the leads at the logger. 5 Check the cabling condition looking for cable breaks. 6 Check the range of the data logger; heat flux can be negative (this could be out of range) or the amplitude could be out of range. 7 Check the data acquisition by applying a mV source to it in the 1 mV range.
The sensor signal shows unexpected variations	1 Check the presence of strong sources of electromagnetic radiation (radar, radio etc.) 2 Check the condition of the shielding. 3 Check the condition of the sensor cable.

Table 11.2.1 *Trouble shooting for HFP01.*

11.3 Appendix on heat flux sensor calibration

The sensitivity E_{sen} of a Heat Flux Sensor is defined as the output V_{sen} for each Watt per square meter heat flowing through it, in a stationary transversal heat flow.

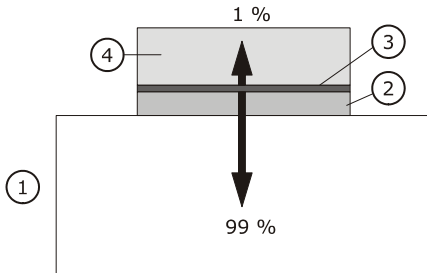The method that is generally applied during production is described below.

Figure 12.3.1 *The calibration method for HFP01; a heat flux sensor (2) is calibrated by mounting it on a metal heat sink (1) with a constant temperature. A film heater (3) is used to generate a well known heat flux. If the thermal conductivity of the sensor is 0.8 W/m.K, at a heat flux of 300 W/m^2, and a sensor thickness is 5 mm, the temperature raise at the heater is 2 degrees. For an un-insulated sensor, this would result in an error of about 20 W/m^2 because of radiative and convective losses. For this reason the heater is again insulated, using foam insulating material. Now 99% of the heat flux passes through the sensor. As a result the accuracy is about 1%. The method has to be validated for application by comparison to a reference calibration as described above.*

The heater calibration is traceable to the "guarded hot plate" of National Physical Laboratory (NPL) of the UK. Applicable standards are ISO 8302 and ASTM C177.
The calibration reference conditions for HFP01 calibration at Hukseflux are:

Temperature: 20 °C
Medium thermal conductivity: 0 W/mK
Heat Flux: 300 W/m^2

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11.4 Appendix on heat transfer in meteorology

Note: All units used in this appendix are clarified in the text. Not all units in this appendix are mentioned in the list of symbols.

Heat is transferred by radiation, convection and conduction.

In most meteorological experiments, the main source of heat during the daytime is the solar radiation. The maximum power of the sun on a horizontal surface is about 1500 W/m^2 in case of a bright sun at noon. The solar radiation is absorbed by the soil, and the resulting heat is used for evaporation of water, heating the air and heating the soil.
At night, when the sun is no longer there, again radiation plays a role; this time the dominant energy flow is from the soil, emitting far infra-red radiation to the sky. The maximum power is about (minus) -150 W/m^2, in case of a clear blue sky.
Other sources than the radiation are usually negligible.
The resulting energy flows through the soil at 5 cm are usually between -100 and +300 W/m^2.

For various practical and theoretical reasons, the heat flux plate cannot be installed directly at the surface. The main reason is that it would distort the flow of moisture, and be no longer representative of the surrounding soil, both from a moisture- and from a thermal/ spectral point of view. Also in case of installation close to the surface, the sensor would be more vulnerable and the stability of the installation becomes an uncertain factor.
For these reasons the flux at the soil surface φ_{surf} is typically estimated from the flux measured by the heat flux sensor, φ_{sen}, plus the change of energy that is stored in the layer above it over a certain time, S.

$$\varphi_{surf} = \varphi_{sen} + S \qquad\qquad\qquad 11.4.1$$

The parameter S is called the storage term.
The storage term is calculated using an averaged soil temperature measurement combined with an estimate of the volumetric heat capacity of the volume above the sensor.

$$S = (T_1 - T_2) \cdot C_v \cdot d / (t_1 - t_2) \qquad\qquad 11.4.2$$

Where S is the storage term, $T_1 - T_2$ is the temperature change in the measurement interval, C_v the volumetric heat capacity, d the depth of installation of the soil heat flux sensors, $t_1 - t_2$ the length of the measurement interval.

At an installation depth of 4 cm, the storage term typically represents up to 50% of the total flux φ_{surf} . When the temperature is measured closely below the surface, the response time of the storage term measurement to a changing φ_{surf} is in the order of magnitude of 20 minutes, while the heat flux sensor φ_{sen} (buried at twice the depth) is a factor 4 slower (square of the depth). This implies that a correct measurement of the storage term is essential to a correct measurement of φ_{surf} with a high time resolution.

Usually the volumetric heat capacity, C_v, is estimated from the heat capacity of dry soil, C_d, the bulk density of the dry soil r_d, the water content (on mass basis), q_m, and C_w, the heat capacity of water.

$$C_v = r_d (C_d + q_m C_w) \qquad\qquad 11.4.3$$

The heat capacity of water is known, but the other parameters of the equation are much more difficult to determine, and are dependent on location and time.

For determining bulk density and heat capacity one has to take local samples and to perform careful analysis. The soil moisture content measurement is difficult and suffers from various errors, so that the estimation of the storage term often is the main source off error in the soil energy balance measurement.

11.5 Appendix on heat transfer in building physics

Note: All units used in this appendix are clarified in the text.
Not all units in this appendix are mentioned in the list of symbols.

Heat is transferred by radiation, convection and conduction.

In most studies of buildings, the main sources of heat during the daytime are the solar radiation and the convective transfer from the outside air to the walls. During the night only convection remains. The maximum power of the sun on a horizontal surface is about 1500 W/m^2 in case of a bright sun at noon. The solar radiation on a non horizontal wall is mainly determined by the direct beam (contrary to the diffuse) solar radiation. The direct beam solar radiation is extremely variable in both intensity and direction during the day.

The convective transport of heat from the wall to the air, φ_{air}, is a function of the heat transfer coefficient, C_{tr}, and the temperature difference between air and sensor, $T_{air} - T_{sen}$.

$$\varphi_{air} = C_{tr} (T_{air} - T_{sen}) \hspace{4cm} 11.5.1$$

In buildings, under indoor conditions we can expect wind speeds of 1 m/s. Working environments will 90% of the cases have wind speeds below 0.5 m/s. Under outdoor conditions up to 30 m/s can be considered normal, with 90% of the cases below 15m/s.

A reasonable approximation of the heat transfer coefficient at moderate wind speeds is given by:

$$C_{tr} = 5 + 4 V_{wind} \hspace{4cm} 11.5.2$$

With C_{tr} in W/m_2K and in V_{wind} m/s.

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11.6 Appendix on HFP03

HFP03 is an ultra sensitive sensor for heatflux measurement of small heat fluxes through soil, walls and building envelopes.

HFP03 has been built specifically for applications where one needs to detect small flux levels, in the order of less than 10 W/m^2. Differences are:

	HFP01	HFP03
Sensitivity	50 µV/ W.m^{-2}	500 µV/ W.m^{-2}
Diameter	80 mm	172 mm
Resistance	2 Ω	18 Ω
Weight including 5 m cable	0.2 kg	0.8 kg

Table 11.6.1 *Differences between HFP01 and HFP03*

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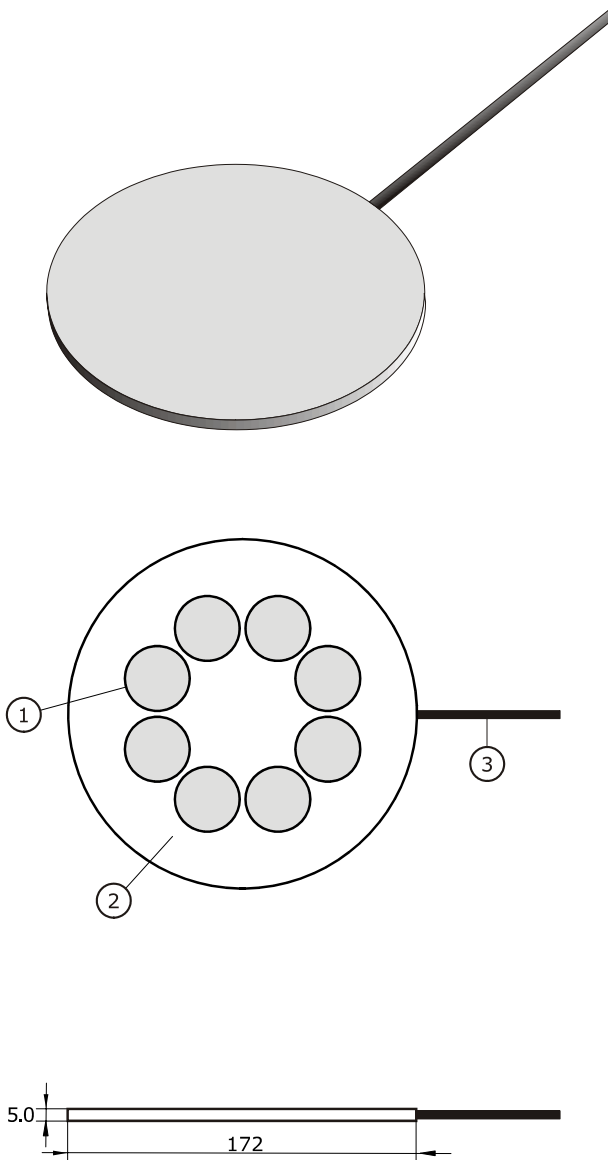
Figure 11.6.1 *HFP03 heat flux plate dimensions:*
(1) sensor area,
(2) guard of ceramics-plastic composite,
(3) cable, standard length 5 m. All dimensions are in mm.

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11.7 CE declaration of conformity

$C\epsilon$

According to EC guidelines 89/336/EEC, 73/23/EEC and 93/68/EEC

We: Hukseflux Thermal Sensors

Declare that the products: HFP01 and HFP03

Is in conformity with the following standards:

Emissions: Radiated: EN 55022: 1987 Class A
            Conducted: EN 55022: 1987 Class B

Immunity: ESD   IEC 801-2;   1984 8kV air discharge
          RF   IEC 808-3;   1984 3 V/m, 27-500 MHz
          EFT   IEC 801-4;   1988 1 kV mains, 500V other

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