HFP01SC

Self Calibrating Heat Flux Sensor[tm]

USER MANUAL

HFP01SC Manual v0811

Edited & Copyright by:

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Hukseflux
Thermal Sensors

Warning:
Putting more than 20 volts across the heater of HFP01SC may result in permanent damage to the sensor

Contents

List of symbols

Heat flux	φ	Wm^{-2}
Thermal conductivity	λ	W/m.K
Voltage output	V	V
HFP01SC sensitivity (factory value)	E_{sen}	$\mu V/Wm^{-2}$
HFP01SC sensitivity (newly found value)	E_{sen2}	$\mu V/Wm^{-2}$
Thermal conductivity dependence of E_{sen}	E_{λ}	mK/W
Time	t	s
Surface area	A	m^2
Deflection error (+ when φ is overestimated)	X	%
Electrical resistance	R	Ω
Thermal resistance	R_{th}	Km^2/W
Measurement at t is 0, 180 seconds	(0), (180)	
Difference before and during heating	Δ	-

Subscripts

Property of thermopile sensor	sen
Property of air	air
Property of the current sensing resistor	cur
Properties of the heater for self test	self
Amplitude	amp
Property during calibration	cal

Introduction

The HFP01SC self-calibrating heat flux sensor[tm] is a sensor intended for high accuracy measurement of soil heat flux.

Also it offers improved quality assurance of the measurement. The on-line calibration (the Van den Bos-Hoeksema method) automatically corrects for various common errors, in particular those due to the non-perfect matching of the thermal conductivity of sensor and soil, and due to variations of the thermal conductivity of the soil caused by varying moisture content.

The self calibration can be used only if the sensor is completely surrounded by at least 40 mm of the object.
A typical measurement location is equipped with 2 sensors for good spatial averaging.

HFP01SC is a combination of a heat flux sensor and a film heater. The primary purpose is to estimate the heat flux through the surrounding soil. The HFP01SC output is a voltage signal that is proportional heat flux through the sensor. The film heater that is mounted on top can be activated to perform a calibration (see chapter 1.3.), resulting in a new calibration factor that compensates for the errors made under the circumstances of that moment. Implicitly also cable connection, data acquisition and data processing are tested. Also errors due to temperature dependence and instability of the sensor are eliminated. The result is a much improved accuracy & quality assurance of the measurement (relative to conventional models such as model HFP01).

The self-calibrating method has been developed at Hukseflux.

The main sensor of HFP01SC is a normal heat flux sensor.
The self calibration is performed by activating the film heater. It is temporarily switched on to perform a heating cycle of around 3 minutes. During this cycle the normal heat flux measurement is disabled.

The self calibration results in an improved sensitivity estimate for the heat flux measurement. The HFP01SC design dates from 1998. In its first years of existence the HFP01SC has rapidly been accepted as the state-of-the-art method for measurement of soil heat flux in meteorology.

In meteorological applications there are two reasons for the popularity of HFP01SC. The first reason is that it offers a higher than usual level of accuracy, the second is that it offers a higher than usual level of quality assurance of the measurement.
The accuracy of soil heat flux measurements very much depends on the matching of the sensor thermal conductivity to that of the surrounding medium. A typical heat flux sensor (Hukseflux 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 sensor 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 second 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 %.

HFP01SC, by using the possibility to calibrate itself, eliminates both errors. For the HFP01SC we estimate +/- 3%, which essentially equals the initial calibration accuracy.

As for the Quality Assurance: measuring with a conventional heat flux sensor, after the sensor is dug in it is assumed that its remains where it is, in good contact with the soil, all cabling in good condition. With the HFP01SC during the calibration implicitly the cabling is checked, thermal connection and also the soil thermal conductivity (as the correction that we make is largely dependent on soil thermal conductivity).

Summarising: when compared to heat flux measurements with conventional heat flux plates, measurement with HFP01SC has a higher accuracy and by applying the measurement a better quality accurance is achieved.
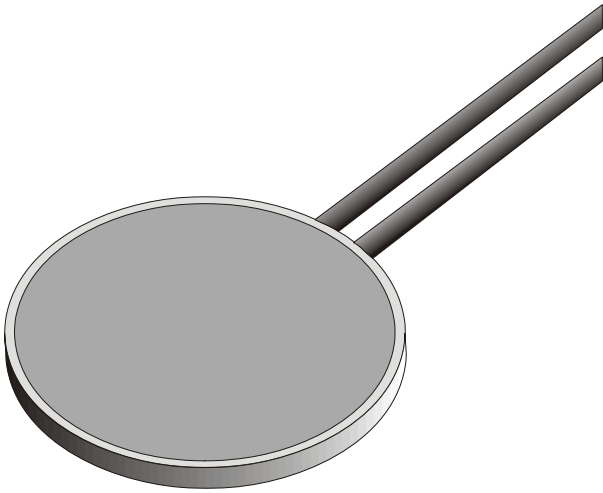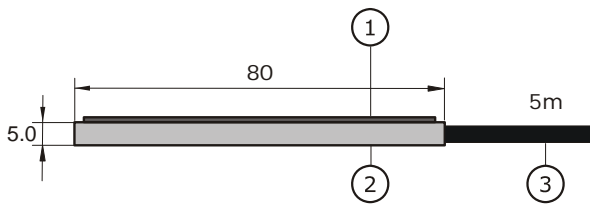
Figure 0.1 *HFP01SC outlook*

Figure 0.2 *HFP01SC dimensions in mm: film heater (1) heat flux sensor body (2), cable (3).*

1   Theory of Self-Calibration

1.1   Introduction

This chapter is written for users that are familiar with the general theory of heat flux sensors and error sources in the heat flux measurement. In case more information on this subject is required, literature (most notably the HFP01 manual) is available free of charge via e-mail as a PDF file. Please request at info@hukseflux.com.

The self calibrating principle can only be used if the sensor is surrounded by at least 40 mm of soil. It is typically used in meteorological applications for measurements of the soil heat flux.

HFP01SC is a combination of a heat flux sensor and a film heater. The heat flux sensor can, as usual, measure the heat flux through the surrounding medium. The output is a voltage signal that is proportional to the local heat flux.
This means that in case of emergency one can use HFP01SC as a normal HFP01.
By activation of the heater, at reguar intervals an updated calibration factor is determined.

> Every new calibration results in an updated calibration factor E_{sen2}.
> The main reasons for this update are changes in soil thermal conductivity (deflection error) and temperature (temperature dependence).

When performing this calibration, typically once every 3 or 6 hours (depending on available power), implicitly also cable connection, data acquisition and data processing are tested. Temperature dependence is eliminated. The result is a dramatically improved accuracy & quality assurance of the measurement (relative to using conventional sensors). The method is generally referred to as the Van den Bos-Hoeksema method.

More detailed explanation follows below.

1.2   Theory on heat flux measurement errors

Using a normal heat flux sensor, there are several common error sources. In soil these are in particular the deflection error and the temperatre dependence. In case of use of HFP01SC, typically in the soil, the resistance error is neglected.

As a first approximation, the heat flux is expressed as:

$$\varphi = V_{sen} / E_{sen} \hspace{4cm} 1.2.1$$

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).*
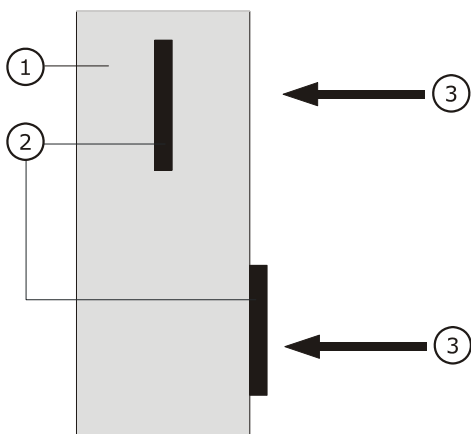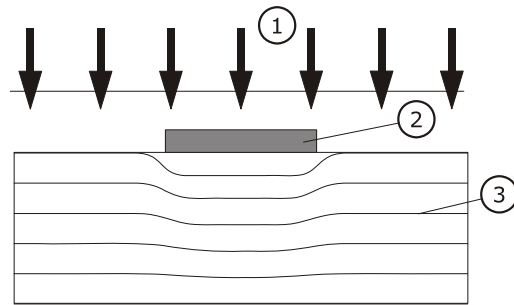
Figure 1.2.2 *The resistance error: a heat flux sensor (2) increases or decreases the total thermal resistance of the object on which it is mounted or in which it is incorporated. An otherwise uniform flux (1) is locally disturbed (3).*

A first order correction of the measurement is:

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

In addition to the resistance error, the fact that the medium thermal conductivity 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 and HFP01SC, 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.
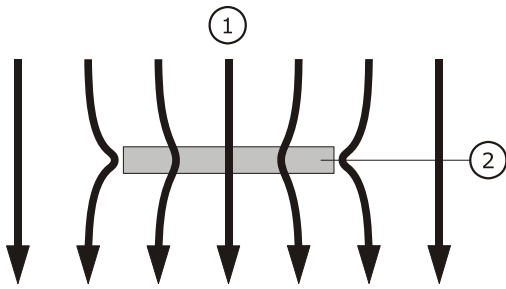
Figure 1.2.3 *The deflection error. The heat flux (1) is deflected in particular at the edges of the sensor. As a result the measurement will contain an error; the so-called deflection error. The magnitude of this error depends on the medium thermal conductivity, sensor thermal properties as well as sensor design.*

In addition, there is a temperature dependence TD reflects the fact that the sensitivity changes with temperature:

$$E_{sen} = E_{sen,\,cal} (1 + TD (T_{cal} - T_{sen})) \qquad\qquad 1.2.4$$

Combining 1.2.3 and 1.2.4:

$$E_{sen} =$$

$$E_{sen,\,cal} \{ (1 + E_\lambda (\lambda_{cal} - \lambda_{med})) + (1 + TD (T_{sen} - T_{cal})) \} \quad 1.2.5$$

Apart from the sensor's own thermal resistance, also contact resistances between sensor and surrounding material are demanding special attention. Essentially any air gaps add to the sensor thermal resistance, at the same time increasing the deflection error in an unpredictable way. In all cases the contact between sensor and surrounding material should be as well and as stable as possible, so that it is not influencing the measurement. It should be noted that the conductivity of air is approximately 0.02 W/m.K, ten times smaller than that of the heat flux sensor. It follows that air gaps form major contact resistances, and that avoiding the occurrence of significant air gaps should be a priority whenever heat flux sensors are installed.
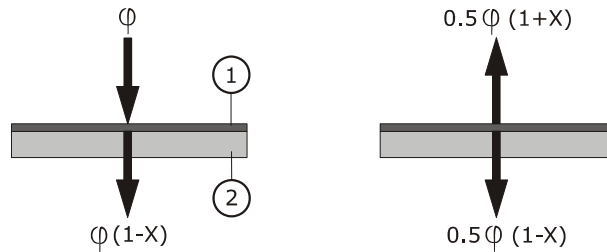
1.3 Self-calibration

Figure 1.3.1 *Explanation of the self-calibrating principle: On the left the normal situation with a heat flux φ. Due to the fact that sensor and medium do not match, the actual flux through the sensor is reduced by a factor (1-X). This error is called deflection error. On the right, the film heater that is mounted on top (1) is activated to generate a well known heat flux φ. The response of the heat flux sensor is measured. In the ideal situation 50% of the generated flux φ would pass through the plate (typically 150 W/m^2). In case of non matching thermal conductivities, a deviation (X) will occur. The essence of this approach is that the flow is divided in an upward flow through undisturbed medium (1+X) and a downward flow through the heat flux sensor (a disturbance) plus underlying medium. The (1-X) signal level however, still represents a 0.5 φ heat flux level of the normal situation of the picture on the left. In other words, the comparison of the measured heat flux to the total artificially generated heat flow is used to correct for the deflection error.*
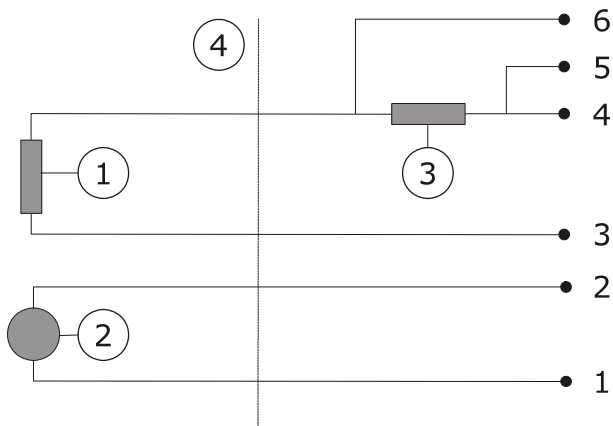
Figure 1.3.2 *electrical connection HFP01SC. Sensor (2) wiring 1 and 2. Heater (1) heater voltage input wires 3 and 4. Heater current measurement, typically performed by putting a 10 ohm resistor (3) in series (not included with HFP01SC), and by measuring the voltage across the resistor, wires 5 and 6. Dashed line (4), sensor on the left and cable and datalogger on the right.*
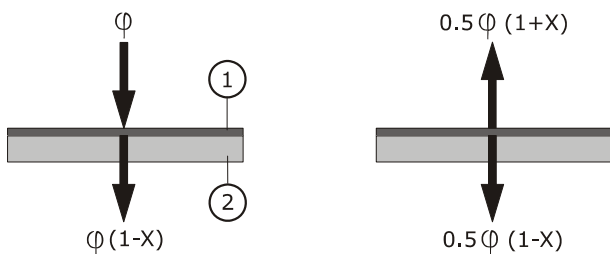
Figure 1.3.3 *An alternative "short cut", explaining the working principle of HFP01SC: in the self-calibrating heat flux plate, a heater is incorporated. The reaction to a pulse in heating represents the currently valid calibration constant. This principle is valid in all environments, and eliminates errors due to the thermal conductivity of the environment (soil moisture) and temperature. In reality, the heat fluxes will deviate from 50%. For calculation of the heat flux in the surrounding medium however, the 50% -50% division remains valid.*

1.4 HFP01SC calculation

The heater generally is switched on every three or six hours. The totoal calibration takes about 6 minutes. During 3 of these 6 minutes, a current is lead through the film resistor for self test, in order to generate a well-known heat flux. The sensor output signal, V_{sen}, is measured. The difference in voltage output of the sensor, V_{amp}, when heating and not heating multiplied by 2 (because only half of the flux passes the sensor) divided by the heat flux, φ_{sen}, is the new sensor sensitivity, E_{sen2}. Typically measurements are done at 0, 180 and 360 seconds.

$$\varphi_{sen} = (V^2_{cur}.R_{self}) / (R^2_{cur}.A_{self}) \qquad\qquad 1.4.1$$

$$V_{amp} = ABS [\{V_{sen} (0) + V_{sen} (360)\}/2 - V_{sen} (180)] \qquad 1.4.2$$

ABS stands for the absolute value.

$$E_{sen2} = 2V_{amp} / \varphi_{sen} \qquad\qquad 1.4.3$$

Concluding:

$$E_{sen\ 2} = 2V_{amp} \ (R^2_{cur}.A_{self})/(V^2_{cur}.R_{self}) \qquad\qquad 1.4.4$$

For HFP01SC's heater a typical value is $A_{self} = 38.85\ 10^{-4}\ m^2$, an R_{cur} is recommended 10 Ω and an R_{self} is sensor specific, around 100Ω. With the mentioned values $\varphi_{sen} = 257.V^2_{cur}$. Please mind that V_{cur} in this case is about 0.1 times the voltage that is applied across the total circuit. At a 12-Volt power supply, V_{cur} would be 1.09 Volt; the heat flux would be 305 W/m^2, half of which would pass the heat flux sensor. Power would be around 0.02 Watt (when switched on every 3 hours).
For type HFP01SC with R_{cur} of 10 Ω and an R_{self} of 100Ω :

$$E_{sen2} = V_{amp} / 129\ V^2_{cur} \qquad\qquad 1.4.5$$

The soil heat flux is calculated as:

$$\varphi = V_{sen} / E_{sen2} \qquad\qquad 1.4.6$$

The factory delivered calibration factor E_{sen} is determined at the factory using an electrically generated heat flux that is forced through the sensor.
In soils, corrections of up to +5 to -20% relative to the factory supplied calibration coefficient can be expected. (the +5% due to temperature dependence)

During the calibration process it is suggested to discard the measured values of the heat flux. This implies that during 6 minutes one could copy the flux value of just before the calibration.
In case very small flux levels are measured, a delay of 10 mintes can be used.

1.5 Additional quality assurance

If possible, additional measures for quality assurance of the measurement can be programmed.

It is suggested to generate an error message if E_{sen2} is larger than the factory delivered E_{sen} by more than 5%, and smaller by more than 20%.

A possible error source is that there has been too much fluctuation between of the heat flux in the soil during the calibration process. As a limit we suggest to allow the measurements at t = 0 and t = 180 to differ no more than 10 % of the signal amplitude during calibration V_{amp} of formula 2.

Summarising: possible quality checks:

1: $E_{sen2} < 0.8\ E_{sen}$
2: $E_{sen2} > 1.05\ E_{sen}$
3: $V_{sen}\ (0) - V_{sen}\ (360) < 0.1\ V_{amp}$

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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.

The soil heat flux measurement with HFP01SC is the most accurate solution available.
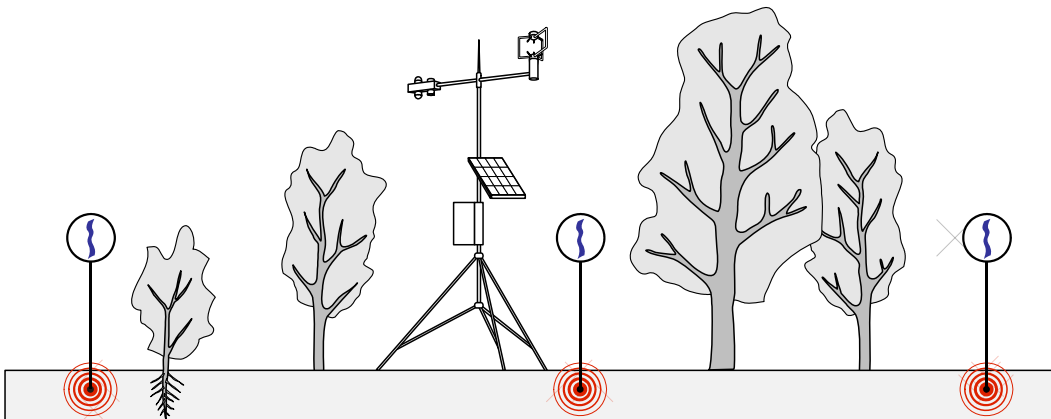
Figure 2.1 *Typical meteorological energy balance measurement system with HFP01SC (typically 2 pieces) installed under the soil.*

In addition to the measurement errors mentioned in the introduction, the heat flux measurement in meteorology suffers from the fact that it is spatially variable.
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.

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.

3 Specifications of HFP01SC

HFP01SC self-calibrating heat flux sensor is intended to be used for determining the heat flux in soil. It is normally used in combination with a suitable measurement and control system, including power supply and relay to activate the self calibration process.

HFP01SC 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.
CE requirements	HFP01SC complies with CE directives
Required depth of insertion	The medium must be all around HFP01SC in good thermal contact. The sensor must be below the surface for at least 40 mm, typically 50 mm
HFP01SC MEASUREMENT SPECIFICATIONS	
Expected accuracy	+/- 3% (heat flux measurements)
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%. This is a statement according to ISO, and is according to the manufacturer too pessimistic.
Thermal conductivity dependence E_λ	-0.07 % m.K/W (nominal value) compensated during self-calibration
Temperature dependence TD	< 0.1%/ °C compensated during self-calibration
HFP01SC SENSOR SPECIFICATIONS	
E_{sen} (nominal)	50 µV/ W. m^{-2} (exact value on calibration certificate) $\lambda_{cal} = 0$, $T_{cal} = 20$ °C E_{sen} is adapted during self-calibration
Sensor thermal conductivity	0.8 W/mK
Sensor thermal resistance R_{th}	< 6.25 10^{-3} Km^2/W

Table 3.1 *List of HFP01SC specifications. (continued on the next page)*

Response time (nominal)	± 3 min (equals average soil)
Range	+ 2000 to - 2000 W.m^{-2}
Non stability	< 1% change per year (normal meteorological use) compensated during self-calibration
Required readout / hardware	1.1 one differential voltage channel or possibly (less ideal) 1.2 one 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. 2 one current measurement (typically realised using a voltage measurement across a 10 ohm resistor. 3 one Relay and timer to switch 12V, 0.1 A power to the heater.
Expected voltage output	Meteorology: -10 to 20 mV (sensor), 0 to 2 V (heater current measuerment)
Heater resistance, area	90 - 110 ohm, 0.003885 m2
Voltage input (heater)	9-15 VDC (nominal), switched
Sensor resistance	2 Ohm (nominal) plus cable resistance
Heating power	1.5 W typically during 180 s, typically every 3 or 6 hours
Power consumption	Average 0.02 (3 hr) or 0.04 (6hr) W
Required programming	$\varphi = V_{sen}/ E_{sen}$
Sensor dimensions	80 mm diameter, 5 mm thickness
Cable length, diameter	5 meters, 5 mm, 2 cables
Weight including 5 m cable, transport dim.	0.3 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	Not applicable
OPTIONS	
Extended cable	Additional cable length x metres (add to 5m)

Table 4.1 *List of HFP01SC specifications. (started on previous page)*

4 Short user guide

Preferably one should read the introduction and the section on theory. Really important items are put in boxes.

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

The first step that is described in paragraph 5 is and indoor test. The purpose of this test is to see if the system works. It can be done in a very simple way.

The second step is to make a final system set-up. This is strongly application dependent, but it usually involves complete programming and automation of the system.
Directions for this can be found in paragraphs 6 to 12.

5 Putting HFP01SC into operation

It is recommended to test the sensor functionality by checking the impedance of the sensor and heater, and by checking if the sensor works, according to the following table: (estimated time needed: 20 minutes)

Check the connection of the heater. Use a multimeter at the 200 ohms range. Measure between two wires that are connected to the heater. 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 heater resistance that is indicated on the calibration certificate.	Infinite indicates a broken circuit; zero indicates a short circuit. Expected value around 110 Ohms.
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 between 2 and 5 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.
If possible put a voltage to the heater between 9 and 12 Volt to see the heater functionality.	The thermopile should react by generating a millivolt output signal.

Table 5.1 *Checking the functionality of the sensor. The procedure offers a simple test to get a better feeling how HFP01SC works, and a check if the sensor is OK.*

The HFP01SC should be connected to the measurement and control system as described in the chapter on the electrical connection.
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.

6 Installation of HFP01SC

HFP01SC 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 HFP01SC is placed the better. When covering HFP01SC with the medium, it should be done such that the medium below and on top is the same. Usually this means that it is safest either to install HFP01SC from the side. When installing by digging a hole, it is recommended to dig the hole some 40 mm deeper than the location of HFP01SC so that eventually the disturbance of the soil is the same above and below the sensor.
For the self-calibrating principle to work properly, the sensor must be installed at least for 40 mm below the surface.
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.

Table 6.1 *General rules for installation of HFP01SC. In case of exceptional applications, please contact Hukseflux.*

7 Maintenance of HFP01SC

Once installed, HFP01SC is essentially maintenance free. Usually errors in functionality will appear as unreasonably large or small measured values.
As a general rule, this means that a critical review of the measured data is the best form of maintenance.

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.

At regular intervals the quality of the cables can be checked.

On a 2 yearly interval the calibration can be checked in an indoor facility.

8 Requirements for data acquisition and control

Capability to measure microvolt signals (sensor signal)	5 microvolt resolution or better
Capability of measuring currents	Around 0.1A, with 1% accuracy, typicaly perfromed by using a 10 Ohm resistor and measurement of the voltage across this resistor.
Capability of switching	9-15 volt at 0.1 A (this is for one sensor only, worst case)
Requirements for power supply of the heater	Capability to supply 9-15 Volt, at 0.1 A In meteorological applications, this is typically done for 3 minutes every three or six hours, depending on the available power. The average required power across the day in this case is 0,02 and 0.04 Watt respectively.
Capability for the data logger or the software	To store data, to subtract and to perform the calculations.

Table 8.1 *Requirements for data acquisition and control.*

9   Electrical connection of HFP01SC

In order to operate, HFP01SC should be connected to a measurement and control system as described above. A typical connection is shown in figure 9.1. For the purpose of making a correct measurement of the heater power there is a current sensing resistor in the wire that leads to the heater. The voltage over a 10-ohm current sensing resistor should be of the order of magnitude of 1 to 2 Volts. The required resistance must be 0.1%, 50ppm or better. We recommend to use a value of 10 ohm, 0.1%, 50ppm, 0.6 Watt or similar.
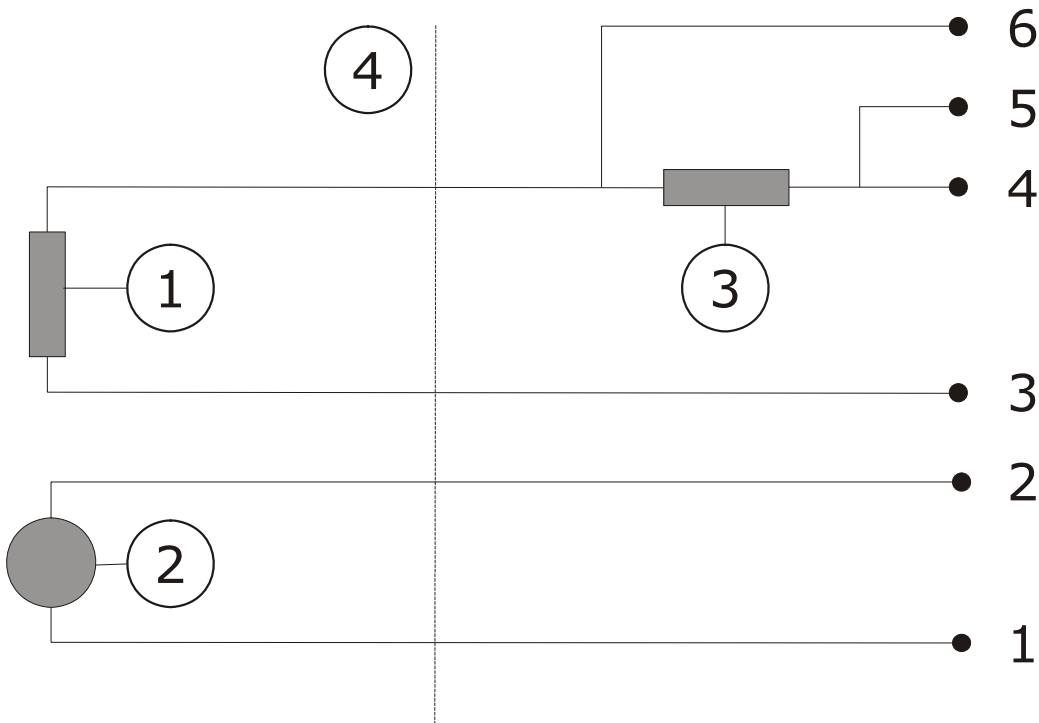

Figure 9.1 *electrical connection HFP01SC. Sensor (2) wiring 1 and 2. Heater (1) heater voltage input wires 3 and 4. Heater current measurement, typically performed by putting a 10 ohm resistor (3) in series, and by measuring the voltage across the resistor, wires 5 and 6. Dashed line (4), sensor on the left and cable and datalogger on the right.*
A relay should be used to switch the heater on and off. The heat flux plate output usually is connected to a differential voltage input. The voltage across the current sensing resistor is also measured by a differential voltage channel. HFP01SC has two separate cables, one for the signal and one for the heater. The colour codes can be found on the calibration certificate.
NOTE: the resistor is normally not part of the delivery.

	Wire colour code	Cable Number
Heat flux sensor +	White	1
Heat flux sensor -	Green	1
Heater	Brown	2
Heater	Green	2

Table 9.1 typical HFP01SC colour code

NOTE: Sensors suplied by Campbell Scientific USA sually have a diferent wiring diagram; see the Campbell manual for ore information. In most cases the 10 ohm is included into th sensor wiring.

Warning:
Putting more than 20 volt across the heater may result in permanent damage to the sensor

10 Programming for HFP01SC

The central formula is:

$$E_{sen\,2} = 2V_{amp}\,(R^2_{cur}.A_{self})/(V^2_{cur}.R_{self}) \qquad\qquad 1.4.4$$

R_{self} and A_{self} are given on the sensor calibration certificate. R_{cur} is user supplied.

The soil heat flux is calculated as:

$$\varphi = V_{sen}/E_{sen2} \qquad\qquad 1.4.6$$

Possible quality assurance tests are:

1: $E_{sen2} < 0.8\ E_{sen}$
2: $E_{sen2} > 1.05\ E_{sen}$
3: $V_{sen}\,(0) - V_{sen}\,(360) < 0.1\ V_{amp}$

In case the heater is not connected, one can work with HFP01SC as if it were a normal heat flux plate, using formula 1.4.6 in combination with E_{sen} as supplied on the sensor calibration certificate.

Sensor specific part, entering R_{self}, R_{cur} and A_{self}, possibly also E_{sen}.	This is typically done in the data logger, but could also be done in a later stage, during processing.	The heater resistance, A_{self} and E_{sen} can be found on the calibration certificate.
Repetitive loop typically 3 or 6 hour repetition.	Measure $V_{sen}(0)$ Store $V_{sen}(0)$	There usually will be a significant signal representing the present heat flux at that moment.
	Temporarily stop the normal soil heat flux measurement	Typically for 6 minutes, can also be stoped for longer.
	Switch heater on	
	Measure the voltage across the current sensing resistor V_{cur}	
	Measure the steady state sensor output $V_{sen}(180)$. Store $V_{sen}(180)$.	
	Switch off the heater	
	Measure the steady state sensor output $V_{sen}(360)$. Store $V_{sen}(360)$.	
	Calculate the average of $V_{sen}(0)$ and $V_{sen}(360)$.	This is to compensate for changes in soil heat flux level.
	Calculate the amplitude V_{amp}.	
	Calculate the new sensor E_{sen2}	
	Do quality assurance tests	
	Start normal soil heat flux measurement again using E_{sen2}	
	Repeat either on user demand or on a regular time schedule	

Table 10.1 *Typical ingredients of a program for measurement and control of HFP01SC.*

11 Appendices

11.1 Appendix on cable extension for HFP01SC

HFP01SC has 2 cables, one for the sensor, and one for the heater.
It is a general recommendation to keep the distance between data logger and sensor as short as possible. Cables generally act as a source of distortion, by picking up capacitive noise.
HFP01SC cable can however be extended without any problem to 100 meters. If done properly, the sensor signal, although small, will not degrade because the sensor impedance is very low. Also connection of the heater is immune to cable extension.
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, or use gold plated waterproof connectors.

Table 11.1.1 *Specifications for cable extension of HFP01SC*

11.2 Appendix trouble shooting

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

It is recommended to start any kind of trouble shooting with a simple check of the sensor and heater impedance. This test can be found in chapter 5. The advantage of this test is that it can be done even if the sensor is dug in.
The second thing to do is a check to see if the thermopile gives a signal. The suggestion is to take a 9-15 Volt battery and to put it across the wires leading to the heater. If these tests still did not give any clue, please contact the supplier.

11.3 CE declaration of conformity

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

We: Hukseflux Thermal Sensors

Declare that the product: HFP01SC

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

Delft,
January 2006