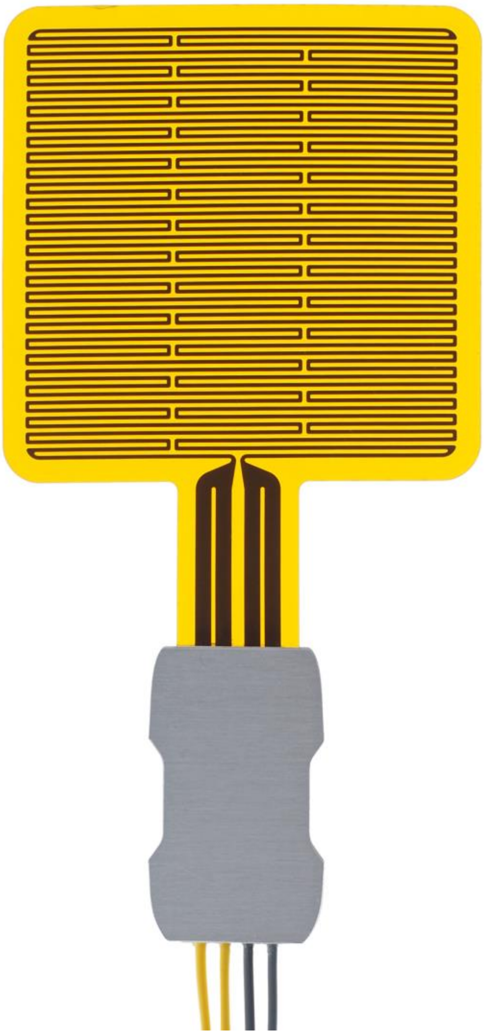
Hukseflux
Thermal Sensors

USER MANUAL **HTR01**

Heater for calibration and verification of performance of FHF-type heat flux sensors



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Warning statements

⚠ Putting more than 24 Volt across the heater wiring can lead to permanent damage to the sensor.

⚠ Do not use "open circuit detection" when measuring the sensor output.

Contents

List of symbols

Quantities	Symbol	Unit
Heat flux	Φ	W/m²
Voltage	U	V
Sensitivity	S	V/(W/m²)
Temperature	T	°C
Thermal resistance per unit area	$R_{thermal,A}$	K/(W/m²)
Area	A	m²
Electrical resistance	R	Ω
Electrical power	P	W

Subscripts

Property of heatsink	heatsink
Property of heater	heater
Property of sensor	sensor
Maximum value, specification limit	maximum

Introduction

HTR01 is a heater with 4-wire connection with a known surface area and electrical resistance. It is used for calibration and functionality checks of FHF-type heat flux sensors. Users can now easily and objectively check their sensor performance before and after use. See also model FHF02SC heat flux sensor with integrated heater.

Measuring heat flux, users may wish to regularly check their sensor performance. A quick check or if you like even a formal calibration is now possible with HTR01 plus some accessories that most laboratories will have in-house. The HTR01 heater has a well characterised a traceable surface area and electrical resistance.

In a typical test setup, the heat losses through the insulation are typically smaller than 3 % and may be ignored. Measuring the heater power (voltage U_{heater} square divided by resistance R_{heater}), and dividing by the surface area A_{heater}, gives the applied heat flux. The heat flux sensor sensitivity S is the voltage output U_{sensor} divided by the applied heat flux.

$$S = (U_{sensor} \cdot R_{heater} \cdot A_{heater})/U_{heater}^2 \qquad \text{(Formula 0.1)}$$

The reproducibility of this test is much improved when using contact material between heater, sensor and heat sink.

HTR01 has unique features and benefits:

- makes it possible to perform a simple test
- guarantees sensor stability
- matches FHF-type heat flux sensors

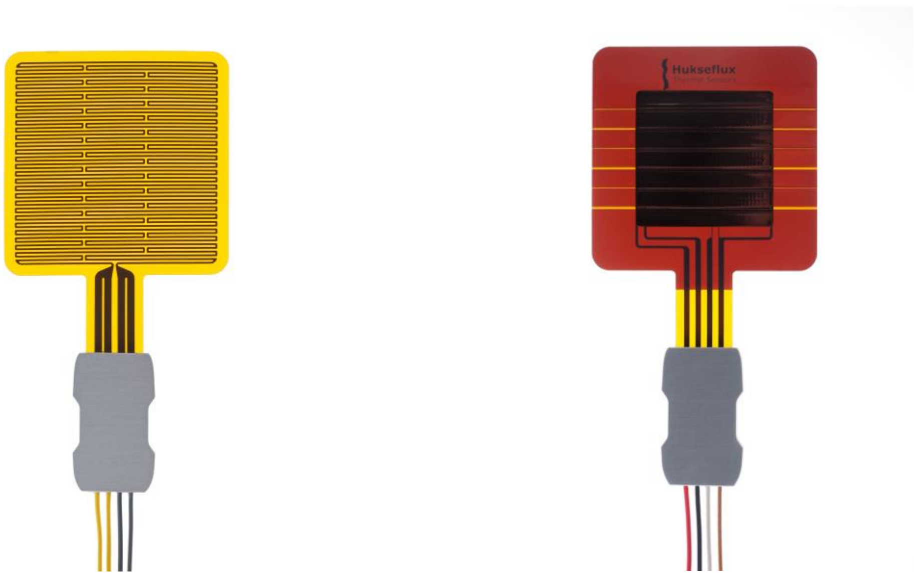

Figure 0.1 *On the left HTR01 heater for calibration and verification of performance of FHF-type heat flux sensors, on the right an FHF02 heat flux sensor to which HTR01 may be applied. See also figure 3.2.1 for dimensions.*

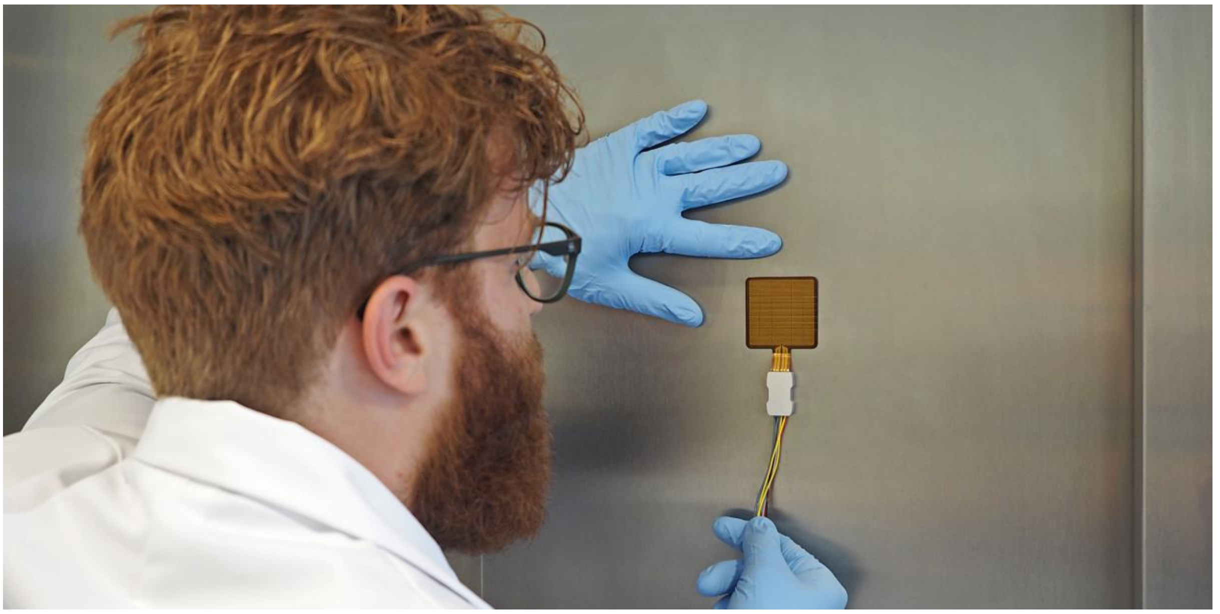

Figure 0.2 *Working with HTR01: application of HTR01 on an FHF-type sensor for performance verification.*

HTR01 is a foil heater. Either it can be used as a general-purpose heater or it can be used in combination with foil heat flux sensors such as FHF01 and FHF02 for test and calibration purposes.

Options:

- longer wire length

See also:

- model FHF02SC heat flux sensor with integrated heater
- model FHF02 general purpose heat flux sensor
- model FHF01 for increased flexibility
- view our complete range of heat flux sensors

1 Ordering and checking at delivery

1.1 Ordering HTR01

The standard configuration of HTR01 is with 2 metres of wire.

Common options are:

- with longer wire length, specify desired wire length in m

1.2 Included items

Arriving at the customer, the delivery should include:

- HTR01 heater with wires of the length as ordered
- product certificate matching the instrument serial number

Figure 1.2.1 *The HTR01 serial number is visible on the strain relief block. HTR01 is delivered with bundled wiring.*

1.3 Quick instrument check

A quick test of the instrument can be done by connecting it to a multimeter:

1. Check the heater serial number on the sticker on the strain relief block against the product certificate provided with the heater.
2. Inspect the instrument for any damage.
3. Check the electrical resistance of the heater between any of the yellow wires and any of the grey wires. Use a multimeter at the 1 kΩ range. Typical resistance should be around 100 Ω. Infinite resistance indicates a broken circuit; zero or a lower than 1 Ω resistance indicates a short circuit.
4. Check the electrical resistance between the 2 yellow wires. These resistances should be in the 0.1 Ω/m range, so 0.2 Ω in case of the standard 2 m wire length. Higher resistances indicate a broken circuit. Repeat this measurement for the 2 grey wires.

2 Instrument principle and theory

HTR01 is a foil heater. Either it can be used as a general-purpose heater or it can be used in combination with foil heat flux sensors such as FHF01 and FHF02 for test and calibration purposes.

2.1 Basic operation

If a voltage U_{heater} is applied to the heater such that an electrical current I_{heater} runs through the heater, the heater power P_{heater} may be calculated as:

$$P_{heater} = U_{heater} \cdot I_{heater} = U_{heater}^2/R_{heater} = I_{heater}^2 \cdot R_{heater}$$

where R_{heater} is the heater electrical resistance. If the heater is placed in a uniform environment (i.e. same medium on both sides of the heater) the applied heat flux Φ in either direction may be calculated as:

$$\Phi = P_{heater}/(2 \cdot A_{heater})$$ (Formula 2.1.1)

where A_{heater} is the heater area. If however the heater is placed in between a thermal insulator and a good thermal conductor the heat flux Φ in the direction of the conductor is:

$$\Phi = P_{heater}/A_{heater}$$ (Formula 2.1.2)

Other cases exist as well. Users need to evaluate which case applies to their situation.

2.2 A self-test for heat flux sensors

In combination with a heat flux sensor such as the FHF01 or FHF02, HTR01 can be used to test the response of the heat flux sensor. To this end HTR01 should be positioned directly on top of the heat flux sensor such that HTR01 can be used to apply a heat flux through the heat flux sensor.

A self-test is started by switching on HTR01, while recording the heat flux sensor output signal and the HTR01 heater power, and finalised by switching HTR01 off. During the heating interval a current is fed through the foil heater, which generates a heat flux proportional to the heater power. The heater power P_{heater} can be measured in several different ways:

- heater voltage and current, $P_{heater} = U_{heater} \cdot I_{heater}$ (Formula 2.2.1)
- heater voltage and known heater resistance, $P_{heater} = U_{heater}^2/R_{heater}$ (Formula 2.2.2)
- heater current and known heater resistance, $P_{heater} = I_{heater}^2 \cdot R_{heater}$ (Formula 2.2.3)

If performed in a four-wire configuration the first method is preferred because it is generally more accurate than the latter two methods, however it requires both a voltmeter and an ammeter instead of just one of the two.

The user must interrupt the normal measurement of the heat flux during the self-test. We recommend that the heat flux value of just before the heating interval is copied for at least 360 s.

Analysis of the heat flux sensor response to the heating, the self-test, serves several purposes:

- first, the amplitude and response time under comparable conditions are indicators of the sensor stability. See 2.4 for application examples.
- second, the functionality of the complete measuring system is verified. For example: a broken cable is immediately detected.
- third, under the right conditions, after taking the sensor out of its normal environment, the self test may be used as calibration. See 2.3 for more details.

2.3 Calibrating heat flux sensors

HTR01 can be used to calibrate heat flux sensors such as the FHF01 and FHF02. It is recommended to recalibrate heat flux sensors at least once every two years. In a typical calibration setup as shown in figure 3, a stack is made of a heatsink, the heat flux sensor to be calibrated, the heater and an insulating material. In such a setup, the heat losses through the insulation may be ignored. In this case all heat generated by HTR01 flows through the heat flux sensor to the heat sink. Measuring the heater power P_{heater}, and dividing by the surface area A_{heater}, gives the applied heat flux:

$$\Phi = P_{heater}/A_{heater} \qquad \text{(Formula 2.3.1)}$$

The heat flux sensor sensitivity *S* is the voltage output U_{sensor} divided by the applied heat flux Φ:

$$S = U_{sensor}/\Phi \qquad \text{(Formula 2.3.2)}$$

The reproducibility of this test is much improved when using contact material (such as glycerol or a thermal paste) between heater, sensor and heat sink.

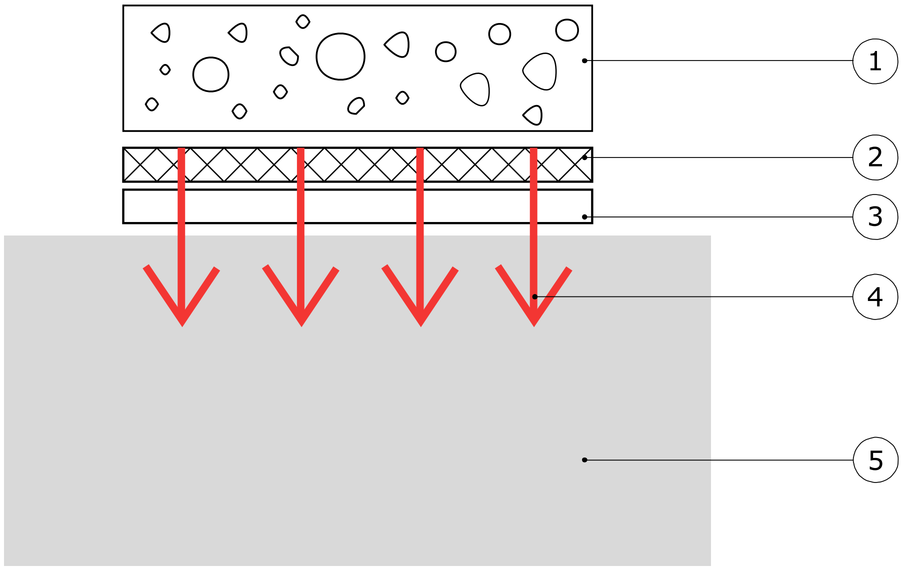

Figure 2.3.1 *Calibration of a heat flux sensor; a typical stack used for calibration consists of a block of metal (mass > 1 kg), for example aluminium (5), the heat flux sensor (3), HTR01 (2) and an insulation foam (1). Under these conditions, heat losses through the insulation are negligible. Heat flux (4) flows from hot to cold.*

2.4 An in-situ test for heat flux sensors

The HTR01 heater can be used to test the stable performance of the heat flux sensors such as the FHF01 and FHF02 at regular intervals without the need to uninstall the heat flux sensor from its application.

For such tests, the HTR01 should be installed on top of the heat flux sensor, preferably on the side of the heat flux sensors with the more insulating medium.

A typical stability check is performed based on the step response of the measured heat flux and sensor temperature to a heat flux applied by HTR01. Upon installing the heat flux sensor and HTR01, a reference measurement should be made. A time trace of the heater power, the measured heat flux and the measured sensor temperature should be stored as reference data. Stable operation of the heat flux sensor can then be confirmed at any time by comparing to the reference measurement. The test protocol consists of the following steps:

1. Make sure that the absolute temperature is similar to that during the reference measurement.
2. Check the heater resistance stability. This can be done accurately by using the four heater wires to conduct a four-point resistance measurement.
3. Record a time trace of the heater power, the measured heat flux and the sensor temperature; the same parameters as in the reference data. Normalise the data by the heater power. Under normal circumstances (if the heater is stable) this process scales with U_{heater}^2.
4. Compare patterns of heat flux and temperature rise and fall. In both cases relative to the values just before before heating.
    - When the signal patterns match, amplitude differences, after correction for heater power, point towards sensor instability. In this case recalibration of the sensor may be required.
    - Non-matching patterns point towards changes in sensor environment. This can for example be the result of a loss of thermal contact between sensor and object.

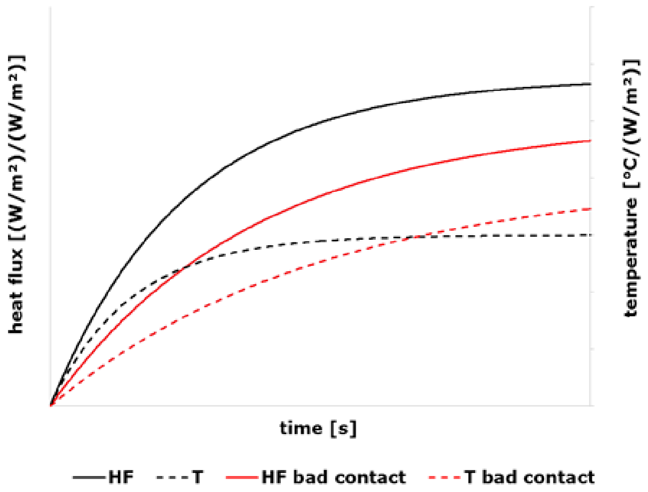

Figure 2.4.1 *In situ sensor stability check. Comparison of responses to stepwise heating relative to reference curves. Normalised to heater power (P) and relative to the heat flux and the temperature just before heating. Solid graphs show heat flux, dotted graphs show temperature. The black HF and T signals are the reference curves at good thermal contact. The sensor looses thermal contact, which results in the red responses: slower response times, lower heat flux and higher temperature rise.*

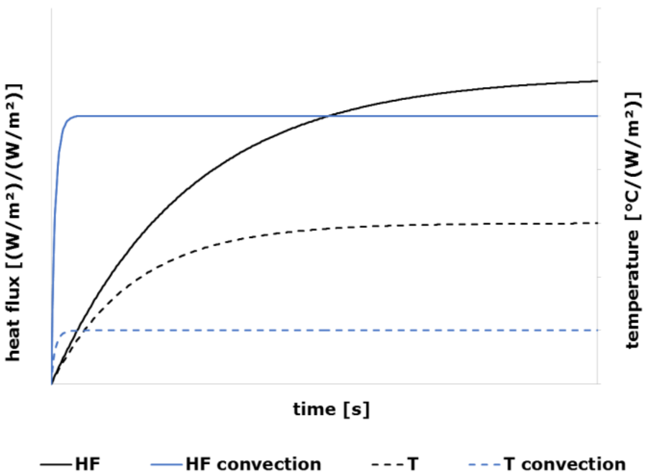

Figure 2.4.2 *In situ sensor stability check. Comparison of responses to stepwise heating relative to reference curves. Normalised to heater power (P) and relative to the heat flux and the temperature just before heating. Solid graphs show heat flux, dotted graphs show temperature. The black HF and T signals are the reference curves at zero wind speed. The sensor is exposed to convection, which results in the blue responses: faster response times at lower heat flux and lower temperature rise.*

3 Specifications of HTR01

3.1 Specifications of HTR01

HTR01 is a heater with 4-wire connection with a known surface area and electrical resistance. It is designed for calibration and functionality checks of FHF-type sensors, but can also be used for general heating purposes.

Table 3.1 *Specifications of HTR01 (continued on next page)*

HTR01 SPECIFICATIONS	
Actuator type	foil heater
Measurement function / required programming	depends on the application
Required readout	1 x current channel and 1 x voltage channel, alternatively 1 x current channel or alternatively 1 voltage channel. currents may be measured using a voltage channel which acts as a current measurement channel using a current sensing resistor heater: 1 x switchable 12 VDC
Rated load on a single wire	≤ 1.6 kg
Rated bending radius	≥ 12 x 10^{-3} m
Operating temperature range	-40 to +150 °C
Heater length and width	(50 x 50) x 10^{-3} m
Heater area	2062 x 10^{-6} m^2
Passive guard area	4 x 10^{-4} m^2
Guard width to thickness ratio	40 m/m
Heater thickness	0.1 x 10^{-3} m
Heater thermal resistance	4 x 10^{-4} K/(W/m^2)
Heater thermal conductivity	0.27 W/(m·K)
Standard wire length	2 m
Heater wiring	4 x copper wire, AWG 24, stranded
Wire diameter	1 x 10^{-3} m
Marking	1 x sticker on strain relief, showing serial number and nominal resistance
IP protection class	IP67
Rated operating relative humidity range	0 to 100 %
Gross weight including 2 m wires	0.10 kg
Net weight including 2 m wires	0.03 kg
Packaging	box of 230 x 170 x 35 mm
ELECTRICAL CHARACTERISTICS	
Heater resistance (nominal)	100 Ω ± 10 % (measured value supplied with each sensor in the production report)
Temperature coefficient of resistance	< 0.02 %/°C
Heater rated power supply	24 VDC
Heater power supply	12 VDC (nominal)
Power consumption during heating interval (nominal)	1.44 W
Self-test duration	360 s (nomimal)
Heating interval duration	180 s (nominal)
Settling interval duration	180 s (nominal)

Table 3.1 *Specifications of HTR01 (continued from previous page)*

INSTALLATION AND USE	
Recommended number of heaters	one per sensor per measurement location
Installation	see recommendations in this user manual
Wire extension	see chapter on wire extension or order sensors with longer wires
VERSIONS / OPTIONS	
With longer wire length	option code = wire length in metres

3.2 Dimensions of HTR01

The image below shows FHF02SC foil heat flux sensor. It has an incorporated heater similar to HTR01, with the same dimensions.
The foil part of HTR01 measures (50 x 50) x 10^{-3} m. The heater itself measures (45 x 45) x 10^{-3} m. The foil of HTR01 is 0.1 x 10^{-3} m thin.

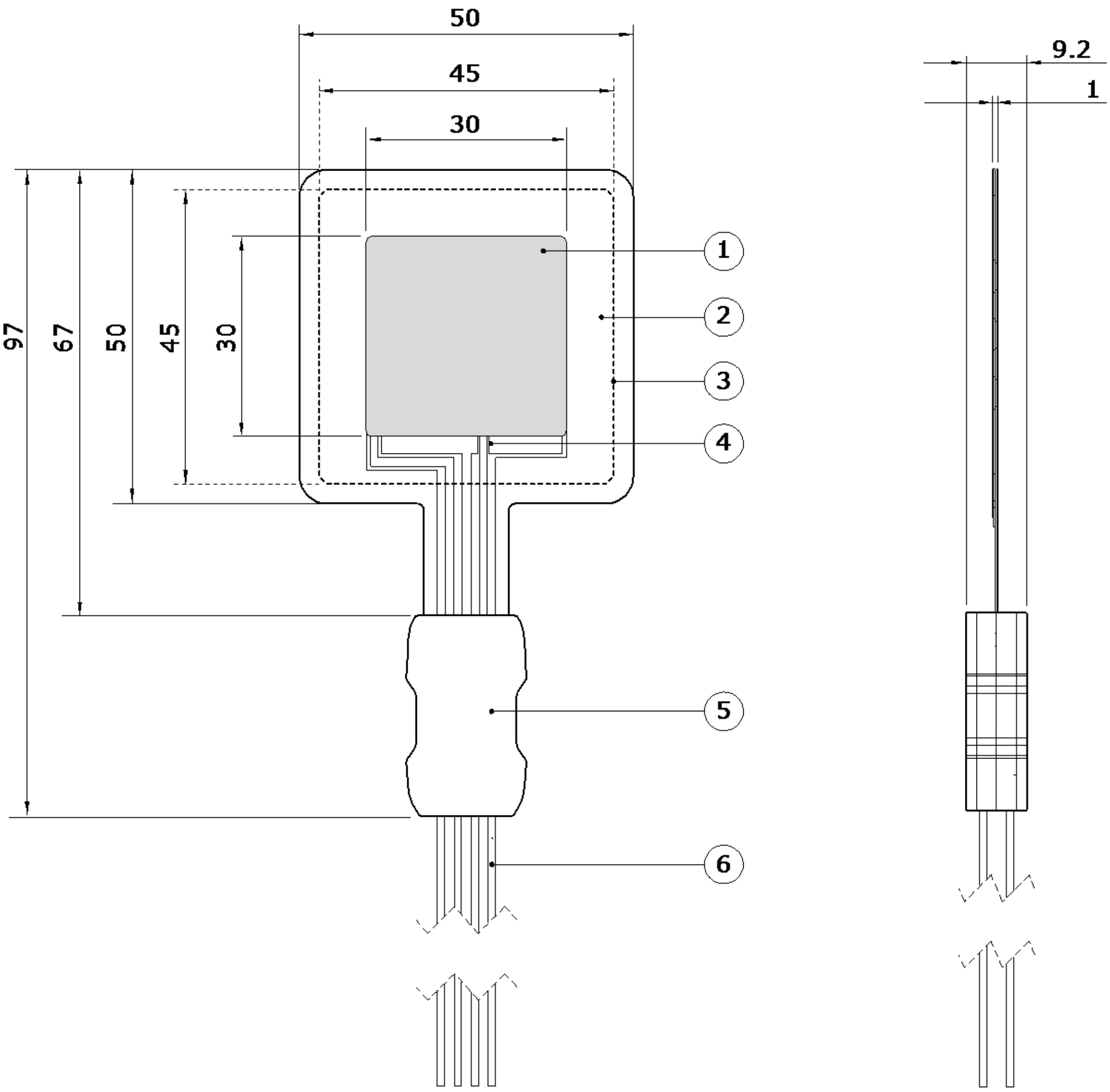

Figure 3.2.1 *FHF02SC heat flux sensor; dimensions in x 10^{-3} m*

(1) sensing area with thermal spreader
(2) passive guard
(3) contour of the heater for self-test
(4) type T thermocouple
(5) strain relief block, showing serial number and sensitivity
(6) wires, standard length 2 m

4 Installation of HTR01

4.1 Site selection and installation

Table 4.1.1 *Recommendations for installation of HTR01 heaters*

Mounting: curved surfaces	when mounting HTR01 on curved surfaces, observe the rated bending radius
Mounting: combination with heat flux sensor	when mounting the HTR01 in combination with a heat flux sensor such as the FHF01 or FHF02, keep the directional sensitivity of the heat flux sensor and the position of the heater in mind
Surface cleaning and levelling	create a clean and smooth surface of (50 x 50) x 10^{-3} m
Mounting: avoiding strain on the heater-to-wire transition	the heater-to-wire transition is vulnerable during installation as well as operation, the user should provide proper strain relief of the wires so that transition is not exposed to significant force first install the wires including strain relief and after that install the heater
Short term installation	avoid any air gaps between heater and surface. Air thermal conductivity is in the 0.02 W/(m·K) range, while a common glue has a thermal conductivity around 0.2 W/(m·K). A 0.1 x 10^{-3} m air gap increases the effective thermal resistance of the sensor by 200 % to avoid air gaps, we recommend thermal paste or glycerol for short term installation use tape to fixate the sensor on the surface. If possible, tape only over the passive guard area (the area without thermopile traces) use tape to fixate the strain relief block of the heater usually the cables are provided with an additional strain relief, for example using a cable tie mount as in Figure 4.1.1
Permanent installation	for long-term installation fill up the space between heater and object with silicone construction sealant, silicone glue or silicone adhesive, that can be bought in construction depots. Use this in combination with the spring-loaded threads we discourage the use of thermal paste for permanent installation because it tends to dry out. silicone glue is more stable and reliable

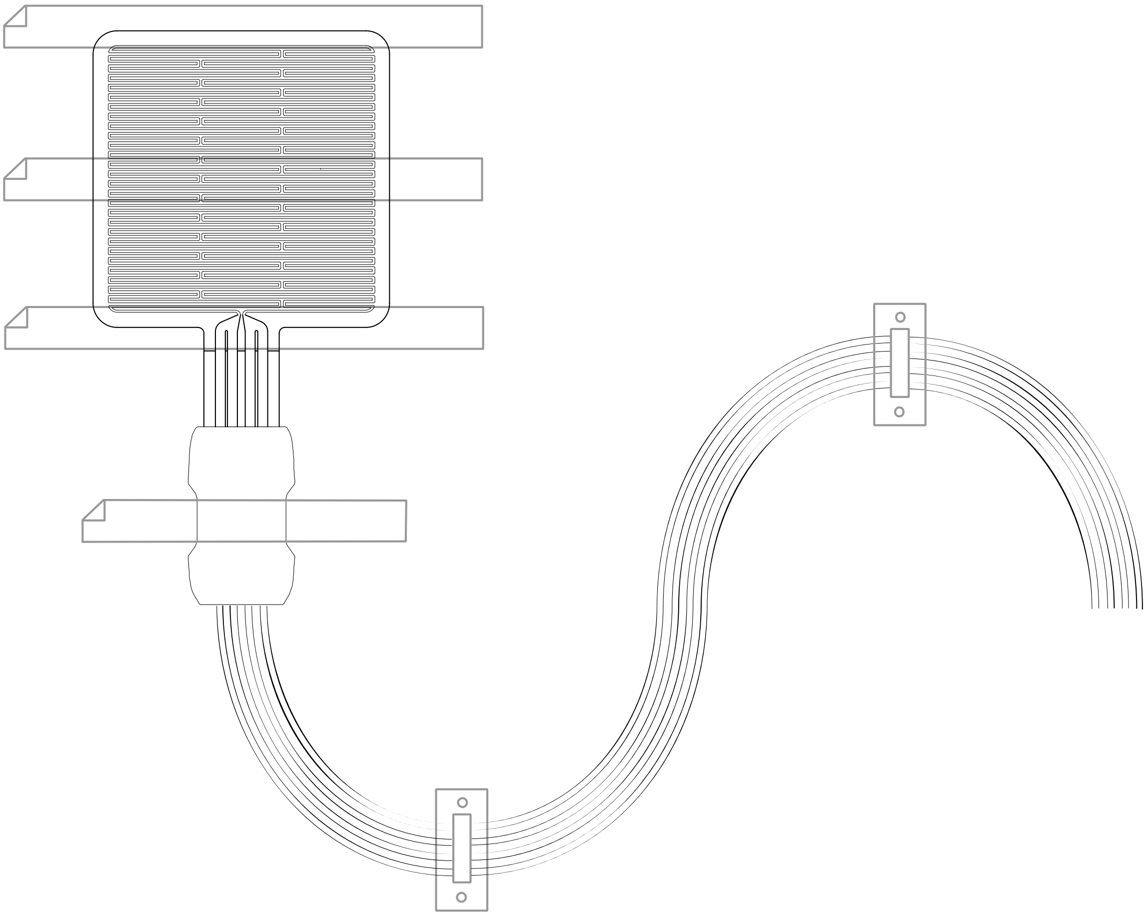

Figure 4.1.1 *Installation of HTR01 using tape to fixate the sensor and the strain relief block. Extra strain relief of the wire is provided using cable tie mounts equipped with double-sided tape as adhesive. As indicated in Table 4.1.1, tapes fixating the sensor are preferably taped over the passive guard area. In this case, a third tape (in the middle) is added for extra support.*

4.2 Electrical connection

To apply a heat flux, HTR01 should be connected to a power supply. If a variable heat flux is required, the heater can either be connected via a solid state relay controlled by a pulse-width modulated (PWM) signal or to a programable power supply (see figure 4.2.1). The HTR01 electrical connections are explained in table 4.2.1 When connecting HTR01, always observe the rated heater voltage. Users must make sure that the used power supply is able to source sufficient current.

Table 4.2.1 *The electrical connections of HTR01. The two yellow wires are equivalent and the two grey wires are equivalent. Together they serve to make a 4-wire connection to the heater.*

WIRE	HEATER
Yellow	heater power [+]
Yellow	heater measure [+]
Grey	heater power [−]
Grey	heater measure [−]

The heat generated by HTR01 can be accurately determined by measuring the heater voltage and current in a four-point measurement. To this end HTR01 has a four-wire connection: two yellow wires and two grey wires. A voltmeter should be used to measure the voltage between one of the yellow and one of the grey leads and an ammeter should be used to measure the current through the other yellow and grey leads that are used to apply a voltage to HTR01. See figure 4.2.1

Alternatively, either a measured voltage or a measured current can be combined with a known heater resistance to compute the heat generated by HTR01. Please refer to section 2.1 for more details on how to compute the heater power and applied heat flux.

Suggested HTR01 wiring is shown in figure 4.2.1. The heater serial number and resistance are shown on the HTR01 product certificate and on the sticker on the strain relief block.

When extending HTR01 wires please consider the thickness and electrical resistance of the wires: too thin wires may lead to excessive heating of the wires themselves.

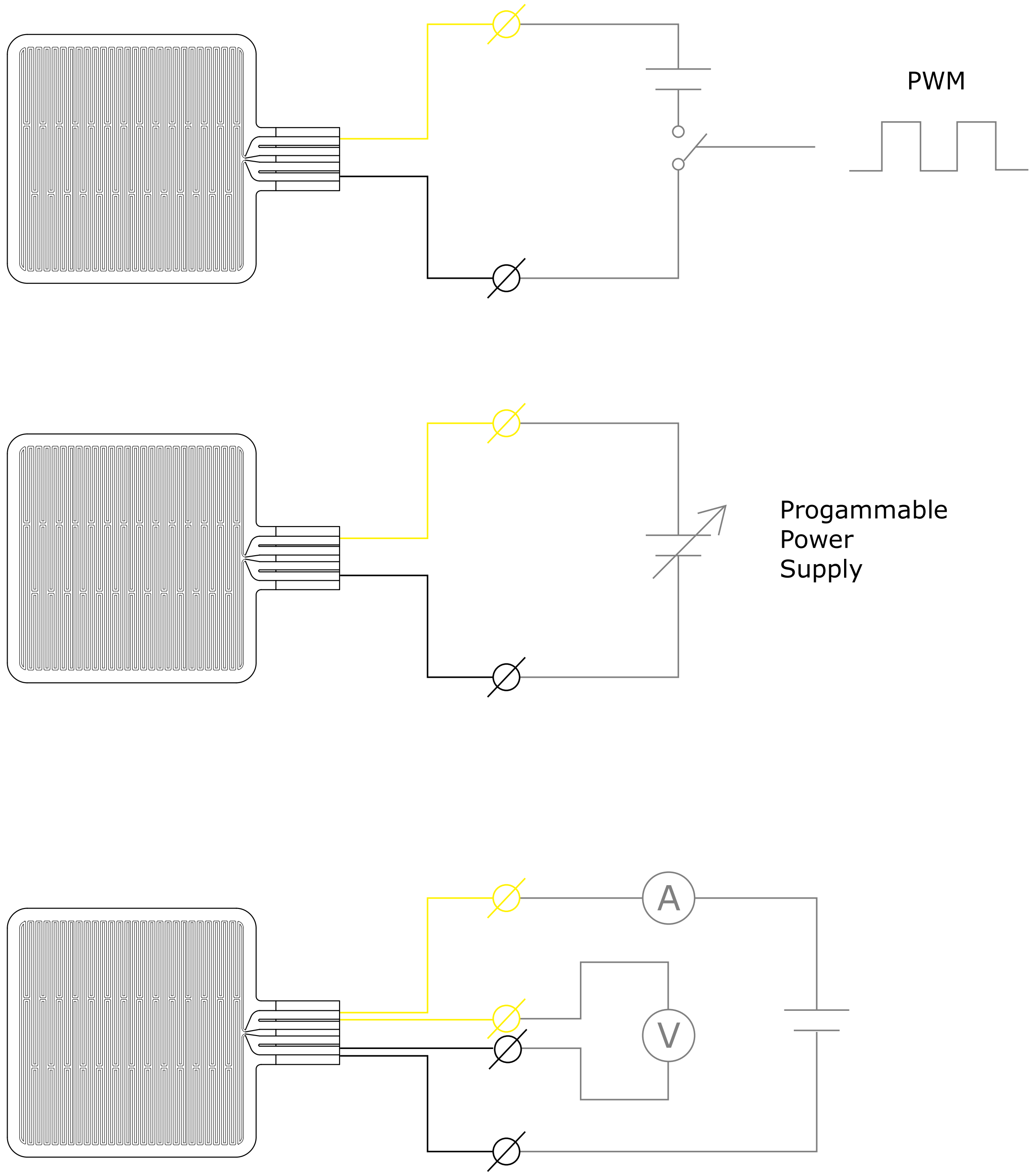

Figure 4.2.1 *Suggested HTR01 heater wiring. Two heater wires are used to carry the heater current; the two others are used to measure the voltage over the heater. There is no significant current flowing though voltage measurement wires so that there is no voltage drop over these wires. This "4-wire connection" measures the true voltage over the heater.*

5 Maintenance and trouble shooting

5.1 Recommended maintenance and quality assurance

HTR01 performs reliably at a low level of maintenance. Unreliable heater output can be detected by scientific judgement, for example by looking for unreasonably large or small measured values. The preferred way to ensure a reliable heater output, is a regular critical review of the measured data.

Table 5.1.1 *Recommended maintenance of HTR01. If possible the data analysis is done on a daily basis*

MINIMUM RECOMMENDED HEAT FLUX SENSOR MAINTENANCE			
	INTERVAL	SUBJECT	ACTION
1	1 week	data analysis	compare measured data to the maximum possible or maximum expected heater power, to other measurements from other redundant instruments and to data previously measured under identical circumstances. Look for any patterns and events that deviate from what is normal or expected. Compare to acceptance intervals.
2	6 months	inspection	inspect wire quality, inspect mounting, inspect location of installation look for seasonal patterns in measurement data
3		lifetime assessment	judge if the instrument will be reliable for another 2 years, or if it should be replaced

5.2 Trouble shooting

Table 5.2.1 *Trouble shooting for HTR01*

General	Inspect the heater for any damage. Inspect the quality of mounting / installation. Inspect if the wires are properly attached to the data logger. Check the condition of the wires. Check the datalogger program in particular if the correct resistance is entered when not measuring according to the 4-wire method. HTR01 resistance and serial number are shown on the product certificate and on the sticker on the strain relief block. Check the electrical resistance of the heater between the wires of the heater. You may use a 4-wire connection. Use a multimeter at the 1000 Ω range. Typical resistance should be the typical heater resistance of 100 Ω ± 10 %. Infinite resistance indicates a broken circuit; zero or a lower than 1 Ω resistance indicates a short circuit. Check the heater resistance value in Ω on the product certificate.
The heater measurements shows unexpected variations	Check the presence of strong sources of electromagnetic radiation (radar, radio). Check the condition of the heater wires. Check if the wires are not moving during the measurement.

5.3 Calibration and checks in the field

The recommended calibration interval of heat flux sensors is 2 years.
Recalibration of field heat flux sensors is ideally done by the sensor manufacturer. You may also calibrate by yourself following chapter 2.3.

On-site field calibration is possible by comparison to a calibration reference sensor. Usually mounted side by side, alternatively mounted on top of the field sensor.

Hukseflux main recommendations for field calibrations are:

1) to compare to a calibration reference of the same brand and type as the field sensor
2) to connect both to the same electronics, so that electronics errors (also offsets) are eliminated
3) to mount all sensors on the same platform, so that they have the same body temperature
4) typical duration of test: > 24 h
5) typical heat fluxes used for comparison: > 600 W/m^2
6) to correct deviations of more than ± 20 %. Lower deviations should be interpreted as acceptable and should not lead to a revised sensitivity

Users may also design their own calibration experiment, for example using a well characterised foil heater.

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6 Appendices

6.1 EU declaration of conformity

We,	Hukseflux Thermal Sensors B.V. Delftechpark 31 2628 XJ Delft The Netherlands

in accordance with the requirements of the following directive:

2014/30/EU	The Electromagnetic Compatibility Directive

hereby declare under our sole responsibility that:

Product model:	HTR01
Product type:	Heater for calibration and verification of performance of FHF-type heat flux sensors

has been designed to comply and is in conformity with the relevant sections and applicable requirements of the following standards:

Emission:	EN 61326-1 (2006)
Immunity:	EN 61326-1 (2006)
Emission:	EN 61000-3-2 (2006)
Emission:	EN 61000-3-3 (1995) + A1 (2001) + A2 (2005)
Report:	08C01340RPT01, 06 January 2009

Eric HOEKSEMA
Director
Delft
December 20, 2017