Hukseflux
Thermal Sensors

USER MANUAL **NF01**

Needle type heat flux and temperature sensor

Warning statements

Follow the installation instructions of this manual. It contains safety notes, rated operating conditions, recommendations on installation and shielding, and requirements for maintenance.

We recommend use of NF01 in a decision-supporting role only, and not to use measurements of NF01 as the sole or main source of information supporting decision making or judgements on safety.

The measurement accuracy of NF01 depends on the quality of its thermal contact to its environment.

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Thermal Sensors

Contents

List of symbols

Quantities	Symbol	Unit
Heat flux	Φ	W/m²
Voltage output	U	V
Sensitivity	S	V·m/K
Temperature	T	°C
Temperature difference	ΔT	°C
Resistance	R	Ω
Thermal conductivity	λ	W/(m·K)
Temperature coefficient	C_1	V·m/K
Temperature coefficient	C_2	V·m/K^2
Temperature coefficient	C_3	V·m/K^3
Temperature coefficient	D_1	W/(m·K)
Temperature coefficient	D_2	W/(m·K^2)
Temperature coefficient	D_3	W/(m·K^3)

Subscripts

N/A

Introduction

NF01 is used for monitoring heat flux and temperature in high temperature environments, typically in walls and shells of blast furnaces and smelters. Measuring heat flux as well as temperature with one sensor is more accurate and practical than using distributed temperature measurements. The same technology is used to manufacture heat flux sensors for different applications.

We recommend use of NF01 in a decision-supporting role only, and not to use measurements of NF01 as the main or sole source of information for judging safety.

NF01 is used for measurement of the energy balance of industrial blast furnaces and smelters, in steel shells as well as in the graphite and brick refractory. It has been applied successfully in iron furnace emergency response systems and in smelters for titania slag production. The sensors inside NF01, a thermopile and a thermocouple, are protected by a fully sealed stainless steel “needle” body. The needle can withstand temperatures up to 700 °C, as well as the aggressive chemical environment of a furnace. Optionally the sensor temperature range can be extended to 1000 °C. The cable is made of PVC. The sensor outputs are heat flux, an analogue voltage signal in the millivolt range, and temperature using a thermocouple type K. The user must know the thermal conductivity of the surrounding material to calculate the heat flux.

Using NF01 is easy. It can be connected directly to commonly used data logging systems. The heat flux Φ in W/m^2 is calculated by dividing the NF01 output, a small voltage U, by the sensitivity S and correcting for the thermal conductivity λ of the environment. The sensitivity S is provided with NF01 on its product certificate.

The measurement function of NF01 is:

$$\Phi = U \cdot \lambda / S \quad \text{(Formula 0.1)}$$

The sensitivity S in V·m/K is temperature T dependent

$$S = C_1 + C_2 \cdot T + C_3 T^2 \quad \text{(Formula 0.2)}$$

The constants C are supplied on NF01’s product certificate.

To work with NF01 the user must know the thermal conductivity of its environment as a function of temperature.

$$\lambda = D_1 + D_2 \cdot T + D_3 T^2 \quad \text{(Formula 0.3)}$$

NF01’s standard diameter is 8 x 10^{-3} m and its standard temperature range is 700 °C. We have made sensors with needle lengths up to 1.5 m. NF01 design is user-specific; needle diameter, needle length and temperature range are designed in cooperation with the user for the specific application.

Common options are:

- longer cable (specify total cable length in m)
- 4 x 10^{-3} m needle diameter
- wire colour codes according to ANSI
- needle lengths (specify L1)
- needle rated operating temperature range up to 1000 °C

For installation the user needs couplings and a set of tools to drill a path for the needle.

See also:
- view our complete product range of heat flux sensors
- our industrial sensors
- NF02 miniature needle type heat flux and temperature sensor

Figure 0.1 *NF01, standard 8 x 10^{-3} m diameter model, with screwed coupling*

Figure 0.2 *NF01, optional 4 x 10^{-3} m diameter model, with screwed coupling*

Figure 0.3 *NF01: special design with positioning piece and connection head*

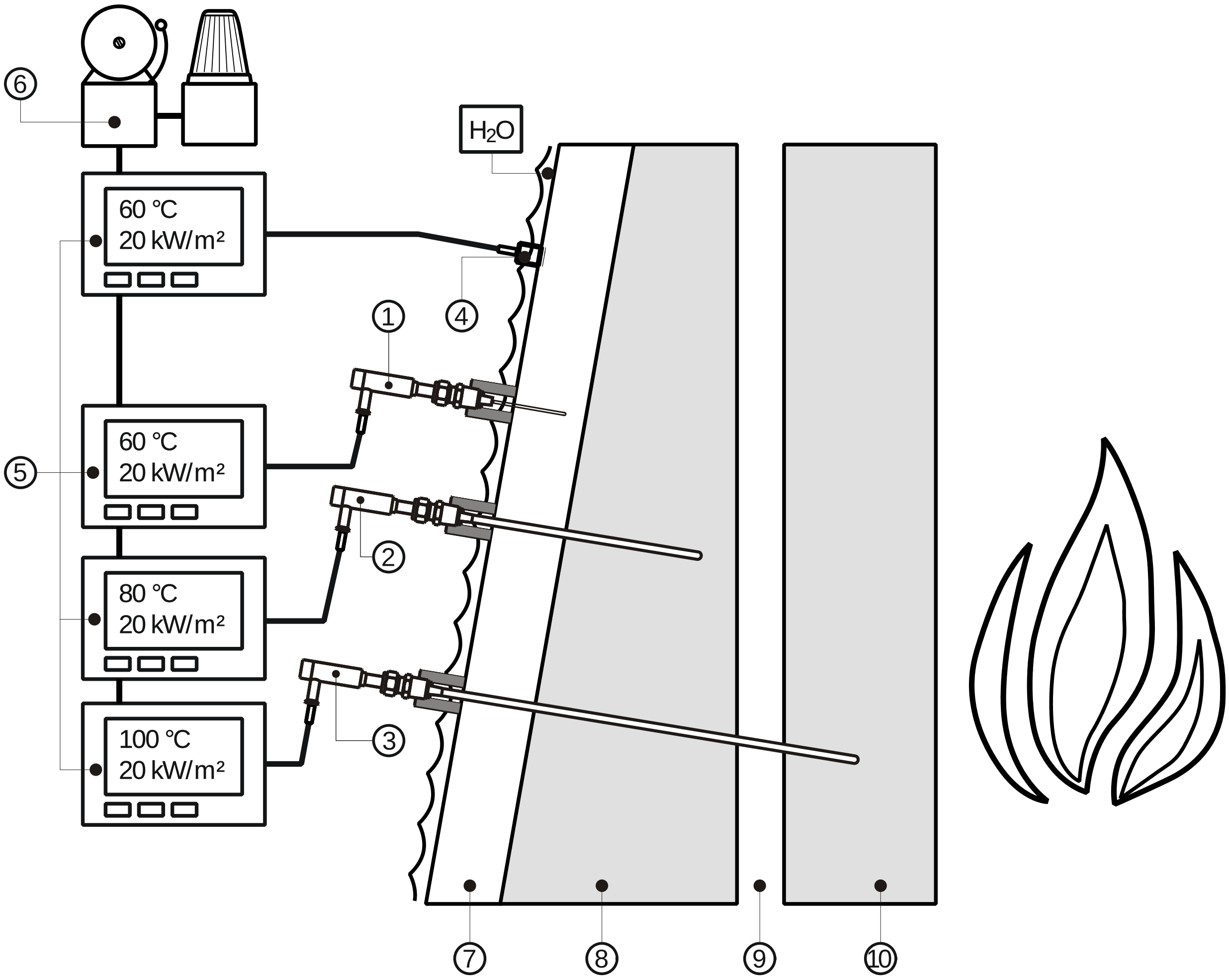


Figure 0.4 *Needle type heat flux and temperature sensors model NF01 applied for process monitoring in a blast furnace: (1),(2) and (3) sensor with standard 8 x 10^{-3} m diameter, (4) sensor with optional 4 x 10^{-3} m diameter, (5) measurement and control system, (6) alarm/warning system, (7) steel shell (water cooled), (8) graphite refractory, (9) mortar, (10) semi-graphite.. The sensors are part of the monitoring system to study energy balance and detect emergencies, for example failure of water cooling or process overheating.*

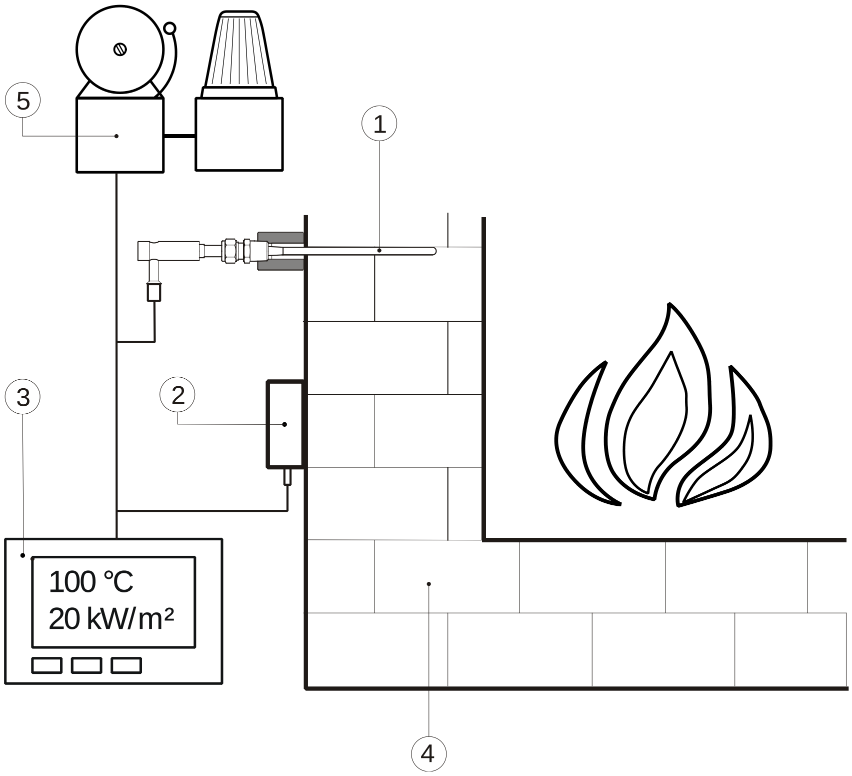


Figure 0.5 *Monitoring of furnaces and ovens: (1) needle type heat flux & temperature sensor NF01, (2) surface heat flux & temperature sensor model HF01 (not discussed in this document), (3) readout unit, (4) brick, (5) alarm/warning system*

1.1 Ordering NF01

The standard configuration of NF01 is with 10 m cable, standard diameter is 8 x 10^{-3} m. Every needle is supplied with a screwed coupling. The wiring colour code is according to IEC, with the thermocouple wires green and white.

For every needle the most important considerations are

- diameter
- needle length
- cable length

Common options are:

- longer cable (specify total cable length in m)
- 4 x 10^{-3} m needle diameter
- wire colour codes according to ANSI (thermocouple wires in yellow and red)
- needle lengths (specify NL)
- needle rated operating temperature range up to 1000 °C

A less common option is:

- EC type examination certificate (ATEX) II 2 G EEx d IIC T6

For installation the user typically needs couplings and a set of tools:

- shell coupling (standard length 50 x 10^{-3} m, other length on request). Couplings should be ordered in the same quantity as NF01 + typically 2 x spare.
- drill centering insert for a 8.5 mm drill. Centering Inserts should be ordered in the quantity of at least 3 per drill diameter.
- 8.5 mm diameter drills for the standard 8 x 10^{-3} m diameter NF01. For other models take a drill diameter of 5 to 6 % higher than the needle diameter. NF01 drills must be adapted to needle length (order different length taking into account the needle lengths and shell coupling lengths). As needles tend to be longer than drills that are available on-site, drills are usually part of the order. The number of drills and limiters ordered depends on the number of different needle lengths, the material to be drilled and the quantity of holes to be drilled. Contact the manufacturer to determine the right quantity.
- limiter for NF01 8.5 mm drill (clamp on NF01 drills to drill to required measurement depth). For other diameters order separate limiters.

1.2 Included items

Arriving at the customer, the delivery should include:

- heat flux and temperature sensor NF01
- including cables of the lengths as ordered
- product certificates matching the instrument serial numbers
- 1 x screwed coupling with every needle

Upon arrival check at least the above including needle lengths and diameters against the order. Perform a functionality check.

1.3 Quick instrument functionality check

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

1 Check the electrical resistance of the heat flux sensor between the black [-] and red [+] wires and the thermocouple between the green [+] and white [-] wires. Use a multimeter at the 100 Ω range. Measure the sensor resistance first with one polarity, then reverse the polarity. Take the average value. Typical resistances are for the cable 0.1 Ω/m (resistance per meter cable) for the total resistance of two wires (back and forth added). For the thermocouple work with 0.7 Ω/m resistance per meter cable. Infinite resistance indicates a broken circuit; zero or a lower than 1 Ω resistance indicates a short circuit.
2. Check if the heat flux sensor reacts to heat: put the multimeter at its most sensitive range of DC voltage measurement, typically the 100 x 10^{-3} VDC range or lower. Expose the sensor to heat, for instance exposing the tip to the flame of a lighter. The signal should read > 0.1 x 10^{-3} V now. Also look at the reaction of the thermocouple to heat.
3. Inspect the instrument for any damage.
4. Check the sensor serial number engraved on the transition piece between sensor and cable, against the certificate provided with the sensor.

2 Instrument principle and theory

NF01 is a sensor that measures heat flux and temperature. It is mainly used to measure heat flux in walls of industrial installations at high heat flux levels. The heat flux sensor inside NF01 is a thermopile which measures a temperature difference along the axis of the NF01 needle. You must know the thermal conductivity of the surrounding material to calculate the heat flux. The sensor outputs are heat flux, an analog voltage signal in the millivolt range, and temperature using a thermocouple type K.

Using NF01 is easy. It can be connected directly to commonly used data logging systems. The heat flux Φ in W/m^2 is calculated by dividing the NF01 output, a small voltage U, by the sensitivity S and correcting for the thermal conductivity λ of the environment. The sensitivity S is provided with NF01 on its product certificate.

The measurement function of NF01 is:

$$\Phi = U \cdot \lambda / S \qquad \text{(Formula 0.1)}$$

The sensitivity S is temperature T dependent

$$S = C_1 + C_2 \cdot T + C_3 T^2 \qquad \text{(Formula 0.2)}$$

For the standard geometry NF01:

$$S = (2.065\,115\,578\,865\,6 - 0.000\,430\,186\,480\,2\ T + 0.000\,001\,319\,347\,3\ T^2) \qquad \text{(Formula 2.1)}$$

The constants C are supplied on NF01's product certificate.

To work with NF01 the user must know the thermal conductivity of its environment as a function of temperature.

$$\lambda = D_1 + D_2 \cdot T + D_3 T^2 \qquad \text{(Formula 0.3)}$$

The measurement accuracy of NF01 depends on the quality of the thermal contact to its environment. The hole in which NF01 is inserted must have a tight fit around the sensor.

For a reliable heat flux measurement, NF01 performs significantly better than a network of distributed individual temperature sensors:

- NF01 creates a single temperature difference signal. This is much more accurate than calculating a heat flux by subtracting two individual temperature measurements. If a heat flux is calculated from two temperature measurements, you subtract two large values with large uncertainties to calculate a small difference, which then has a similarly large uncertainty.
- NF01 sensors can be quickly installed; contrary to spatially distributed temperature sensors, the relative position of the sensors used for the temperature difference measurement is already determined during manufacturing. The exact depth of insertion is not a critical factor determining the accuracy of this relative position. Installation can be done quickly with little training.
- NF01 sensors are fully exchangeable. Contrary to spatially distributed temperature sensors, the sensors in the NF01 are “matched pairs”. This is essential to attain the best possible temperature difference measurement.
- NF01 has a fast heat flux response time: the high accuracy makes it possible to measure a temperature difference over a small distance.
- NF01 is durable; the swaged thick-wall needle last longer than normal sensors.

NF01’s standard diameter is 8 x 10^{-3} m and its standard temperature range is 700 °C. We have made sensors with needle lengths up to 1.5 m. NF01 design is user-specific; needle diameter, needle length and temperature range are designed in cooperation with the user for the specific application.

3 Specifications of NF01

3.1 Specifications of NF01

NF01 measures heat flux and temperature. The heat flux sensor inside NF01 is a thermopile which measures a temperature difference along the axis of the NF01 needle. The measurement accuracy of NF01 relies on good thermal contact to its environment. You must know the thermal conductivity of the surrounding material to calculate the heat flux. The sensor outputs are heat flux, an analogue voltage signal in the millivolt range, and temperature using a thermocouple type K. NF01 is a passive sensor; it does not need power. It can only be used in combination with a suitable measuring system. The sensor should be used in accordance with the recommended practices this manual.

Table 3.1 *Specifications of NF01 (continued on next pages)*

NF01 SPECIFICATIONS	
Sensor type	needle type heat flux and temperature sensor
Heat flux sensor	thermopile
Measurand	heat flux
Measurand in SI units	heat flux density in W/m^2
Rated measurement range	0.05 to 50 x 10^3 W/m^2 (typical)
Temperature sensor	thermocouple type KX
Temperature sensor specification	ANSI MC96.1-1982 / EN 60584
Measurand	temperature
Measurand in SI units	temperature in °C
Measurement range	-30 to 700 °C
Rated operating temperature range Sensor Sensor optional Cable	 -30 to +700 °C -30 to +1000 °C -30 to +85 °C
Measurement function / required programming	$\Phi = U \cdot \lambda / S$ $S = C_1 + C_2 \cdot T + C_3 T^2$ $\lambda = D_1 + D_2 \cdot T + D_3 T^2$
Sensitivity for standard geometry	S = (2,0651155788656 - 0,0004301864802 T + 0,0000013193473 T^2)
Required input to the measurement equation	thermal conductivity of the material surrounding the needle as a function of temperature $\lambda = D_1 + D_2 \cdot T + D_3 T^2$
Recommended number of sensors	2 per measurement location
Sensitivity (nominal)	2 x 10^{-6} V·m/K
Response time (95 %)	depends on surrounding material
Expected voltage output	depends on heat flux and measurement environment typically 5 x 10^{-3} V
Required readout	heat flux sensor: 1 x differential voltage channel or 1 x single ended voltage channel temperature sensor: 1 x Type K differential thermocouple channel or 1 x Type K single ended thermocouple channel both with input resistance > 10^6 Ω
IP protection class needle coupling and cable	IP68 IP64
Sensor design	swaged SS310 sheath Inconel 600 sheath for high temperature option
Rated operating relative humidity range	0 to 100 %

Table 3.1 *Specifications of NF01 (started on previous page, continued on the next page)*

Required sensor power	zero (passive sensors)
Needle length	specified by the user
Needle diameter Needle diameter optional	8×10^{-3} m 4×10^{-3} m
Standard cable length	10 m (see options)
Cable type	PVC signal cable with shield and drain wire
Heat flux sensor resistance	0 Ω (nominal)
Heat flux sensor cable resistance	0.1 Ω/m (nominal)
Thermocouple resistance	0 Ω (nominal)
Temperature sensor cable resistance	0.7 Ω/m (nominal)
Cable diameter	7.5×10^{-3} m
Marking	1 x engraving on the needle to cable transition piece, showing serial number 1 x sticker at cable end, showing serial number
Net weight	3 kg (with 10 m cable)
Equipment status according to directive 2014/34 EU	NF01 is a passive sensor which does not have its own source of ignition. It becomes equipment in the sense of Article 2 of the directive only when operating in combination with other equipment.
GENERAL INSTALLATION AND USE	
Location	see recommendations in this user manual
Installation	see recommendations in this user manual The measurement accuracy of NF01 depends on the quality of its thermal contact to its environment. Make sure there is good thermal contact.
Cable extension	cables may be extended under user responsibility employing a connection box certified for use in its operating environment
MEASUREMENT TRACEABILITY	
Traceability	to ITS90 and distance
Product certificate	included (showing traceability and dimensional verification during production)
On-site testing	is possible by comparison to a reference sensor of the same type, mounted side by side under similar conditions.
Temperature sensor tolerance class	IEC Tolerance class EN60584-2: Type KX, class 2
Temperature sensor error limits	ASTM E230-ANSI MC96.1: Type KX, standard limits
MEASUREMENT ACCURACY	
Uncertainty of the measurement	statements about the overall measurement uncertainty can only be made on an individual basis.

Table 3.1 *Specifications of NF01 (started on previous 2 pages)*

VERSIONS / OPTIONS	
Sensor design	NF01 design is user-specific; needle diameter, needle length and temperature range are designed in cooperation with the user for the specific application
Order code	NF01 / needle diameter in x 10^{-3} m / needle length in m / cable length in m
Option	longer cable (specify total cable length in m)
Option	4 x 10^{-3} m needle diameter
Option	wire cladding colour codes according to ANSI
Option	needle lengths (specify NL)
Option	needle rated operating temperature range up to 1000 °C
Option	EC type examination certificate (ATEX) II 2 G EEx d IIC T6
SPARE PARTS	
Spare part	NF01 screwed coupling (one model for all needle diameters)
PARTS FOR INSTALLATION	
Shell coupling	standard length 50 x 10^{-3} m other length on request couplings should be ordered in the same quantity as NF01+typically 2 spares optionally other lengths are available
Drill centering insert for an 8.5 mm drill	drill centering inserts should be ordered in the quantity of at least 3 per drill diameter. optionally inserts for other drill diameters are available
Drill 8.5 mm diameter	for the standard 8 x 10^{-3} m diameter NF01. order different length taking into account the needle lengths and shell coupling lengths optionally other drill diameters are available. Take a drill diameter of 5 to 6 % higher than the needle diameter.
Limiter for NF01 for a 8.5 mm drill	clamp on NF01 drills to drill to required measurement depth. optionally limiters for other drill diameters are available

3.2 Dimensions of NF01

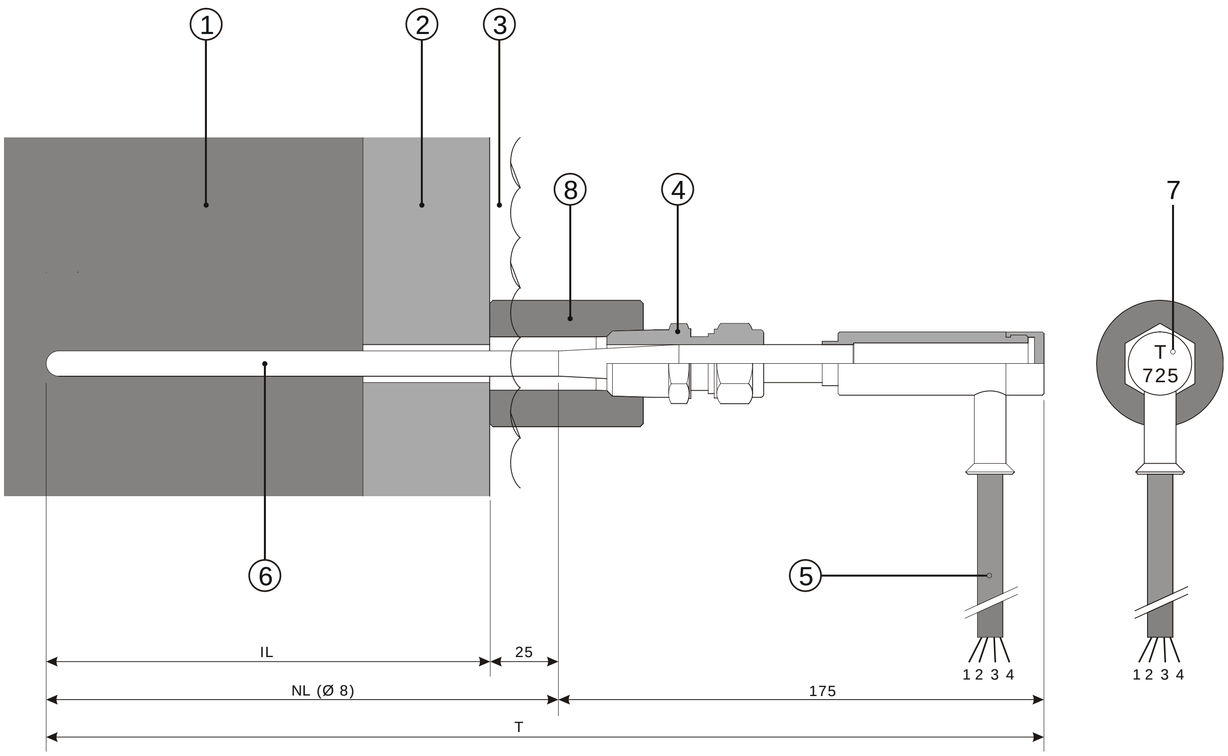


Figure 3.2.1 *NF01 standard version for operation in the furnace lining (graphite or brick) part of the furnace wall: (2) steel shell, (3) water, (1) graphite, (8) shell coupling, (4) screwed coupling, (5) cable, (6) needle type heat flux and temperature sensor.*

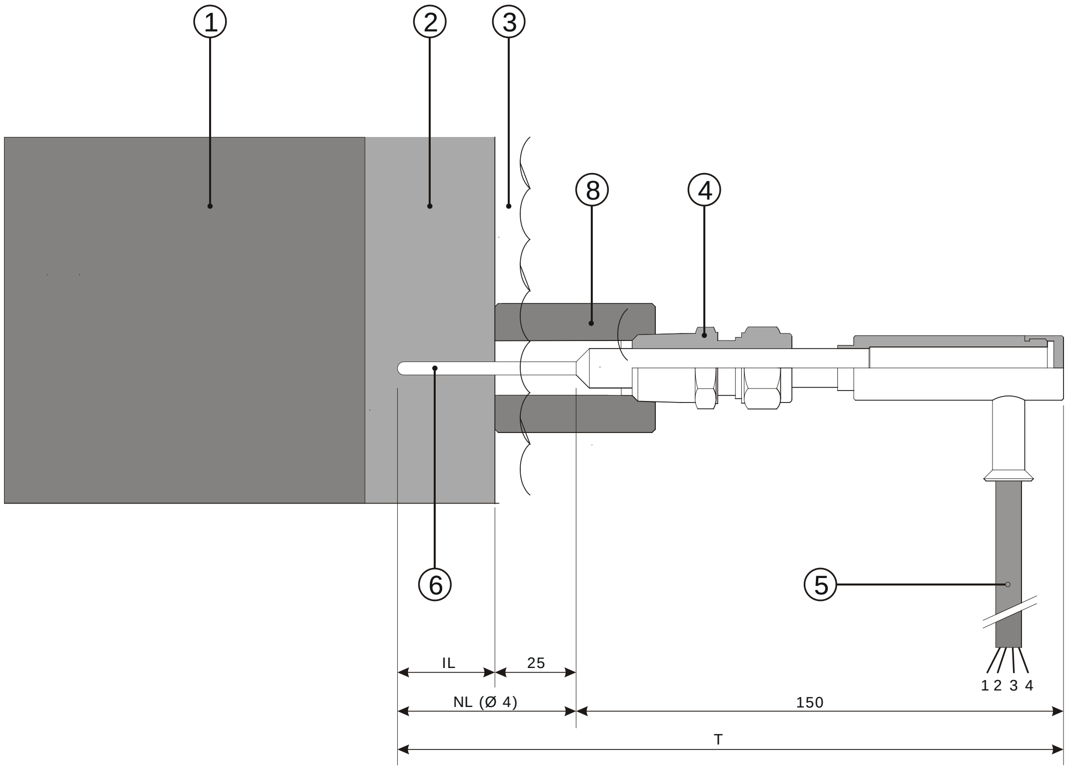


Figure 3.2.2 *NF01 optional 4 x 10^{-3} m diameter version for operation in the water cooled part (shell) of the furnace wall: (2) steel shell, (3) water cooled, (1) graphite, (8) shell coupling, (4) screwed coupling, (5) cable, (6) needle type heat flux and temperature sensor.*

4 Installation of NF01

4.1 Electrical connection

A heat flux sensor should be connected to a measuring system, typically a so-called datalogger. NF01 is a passive sensor that does not need any power, neither for the heat flux sensor, nor for the temperature sensor. Cables may act as a source of distortion, by picking up capacitive noise. We recommend keeping the distance between a datalogger or amplifier and the sensor as short as possible.

Table 4.1.1 *The electrical connection of NF01. Standard IEC colour code; the IEC code for thermocouple K is green / white.*

WIRE	
Red	heat flux signal [+]
Black	heat flux signal [−]
Green	thermocouple type K [+]
White	thermocouple type K [−]
Blank	shield

Table 4.1.2 *The electrical connection of NF01. Optional ANSI colour code; the ANSI code for thermocouple K is yellow / red.*

WIRE	
Orange	heat flux signal [+]
Blue	heat flux signal [−]
Yellow	thermocouple type K [+]
Red	thermocouple type K [−]
Blank	shield

4.2 Site selection and installation

Table 4.2.1 General r*ecommendations for use of NF01 heat flux sensors*

Location	NF01 sensors are located at carefully selected locations, and typically at several depths (using different needle lengths). The measurement accuracy of NF01 depends on the quality of its thermal contact to its environment. Make sure there is good thermal contact.
Performing a representative measurement	we recommend using > 2 sensors per measurement location as well as sensors at different depths. This redundancy also improves the assessment of the measurement accuracy.
Signal amplification	ask the manufacturer for recommendations for signal amplification / conversion

Table 4.2.2 *Recommendations for installation of NF01 heat flux sensors*

1	weld "shell couplings" on the metal shell, test the weld to local standards The standard coupling length is 50 x 10^{-3} m. Couplings can also be ordered in different lengths. The coupling material is carbon steel. Welding should be all-round to guarantee that the whole assembly is gas-tight.
2	temporarily put "drill centering inserts" on the shell coupling to guide the drill. A centering insert can be removed after drilling. Using a centering insert will guarantee that the needle can later be installed without problems onto the shell couplings.
3	drill through the metal shell using a standard 8.5 mm drill (for the standard 8 x 10^{-3} m diameter needle, adapted diameter for other needle diameters. The drill diameter should be close to the needle diameter to ensure good thermal contact.
4	drill through the wall or lining to the required depth for the needle at that position using specially supplied "NF01 drills" with "NF01 drill limiters" Drill limiters are clamped at the right distance from the drill tip taking into account the needle length as well as the position of the couplings.
5	remove the "drill centering inserts"
6	screw the NF01 screwed coupling on to the shell coupling. if possible use locally approved thermal paste to promote thermal contact between the hole and the needle Test the coupling to local standards
7	insert the NF01, fasten the screwed coupling

5 Recommended practices for use

5.1 Short user guide

Table 5.1 *Recommended practices for use*

NF01 RECOMMENDED PRACTICES FOR USE		
1	Read the user manual	
2	Determine options	choose needle lengths, cable lengths, needle diameters, temperature range, cable colour code. choose spare sensors
3	Design mounting and amplification	see the chapter on electrical connection and installation
4	Determine mounting and tooling requirements	drills, couplings, limiters, use of locally approved thermal paste
5	Ordering	
6	Unpack NF01	check shipment contents (see paragraph on included items) against the order
7	Check sensor functionality	see the paragraph on the functionality test
8	Install	see the directions on installation
9	Check performance	verify by comparing measured heat flux to a reference measurement at a spot where sensors of the same type can be mounted side by side
10	Check inspection / maintenance / verification procedures	check the maintenance schedule

6 Maintenance and trouble shooting

6.1 Recommended maintenance and quality assurance

NF01 measures reliably at a low level of maintenance, but does require frequent inspection. Unreliable measurement results are detected by scientific judgement, for example by looking for unreasonably large or small measured values. The preferred way to obtain a reliable measurement is a regular critical review of the measured data, preferably checking against other (nearby) measurements.

Table 6.1.1 *Recommended maintenance of NF01. 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 and inspection	compare measured data to the maximum possible or maximum expected heat flux and to other measurements for example from nearby or redundant instruments. Historical records can be used as a source for expected values. Look for any patterns and events that deviate from what is normal or expected. Compare to acceptance intervals
2	6 months	inspection	inspect, inspect cable quality, inspect mounting, inspect location of installation
3	2 years	on-site check	check the sensor in the field, see following paragraphs
4		lifetime assessment	judge if the instrument will be reliable for another 2 years, or if it should be replaced

6.2 Trouble shooting

Table 6.2.1 *Trouble shooting for NF01*

General	Inspect the sensor 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 cable. Inspect the connection of the shield (typically connected at the datalogger side). Check the datalogger program in particular if the right sensitivity is entered. NF01's sensor serial number is engraved on the transition piece between sensor and cable. The sensitivity can be found on the calibration certificate. Check if the right thermal conductivity of the environment is entered. Check the electrical resistance of the heat flux sensor between the black [-] and red [+] wires and the thermocouple between the green [+] and white [-] wires. Use a multimeter at the 100 Ω range. Measure the sensor resistance first with one polarity, then reverse the polarity. Take the average value. Typical resistances are for the cable 0.1 Ω/m (resistance per meter cable) for the total resistance of two wires (back and forth added). For the thermocouple work with 0.7 Ω/m resistance per meter cable. Infinite resistance indicates a broken circuit; zero or a lower than 1 Ω resistance indicates a short circuit.
The sensor does not give any signal	Check if the heat flux sensor reacts to heat: put the multimeter at its most sensitive range of DC voltage measurement, typically the 100 x 10^{-3} VDC range or lower. Expose the sensor to heat, for instance exposing the tip to the flame of a lighter. The signal should read > 0.1 x 10-3 V now. Check the reaction of the thermocouple sensor to heat. Check the data acquisition by replacing the sensor with a spare unit.
The sensor signal is unrealistically high or low	Check the cable condition looking for cable breaks. Compare data to data coning from nearby sensors, for example sensor mounted at the same location but at a different depth. Check the data acquisition by applying a 1 x 10^{-6} V source to it in the 1 x 10^{-6} V range. Look at the measurement result. Check if it is as expected. Check the data acquisition by short circuiting the data acquisition input with a 10 Ω resistor. Look at the output. Check if the output is close to 0 W/m^2.
The sensor signal shows unexpected variations	Check the presence of strong sources of electromagnetic radiation (radar, radio). Check the condition and connection of the shield. Check the condition of the sensor cable. Check if the cable is not moving during the measurement.

6.3 NF01 diagnostics

The following tables are used for checking and trouble shooting NF01.

Table 6.3.1 *Resistance checks for diagnostics of NF01 with IEC wire cladding colour. For the optional ANSI colour code, see the paragraph on electrical connection.*

WIRE	WIRE	RESISTANCE ACCEPTANCE INTERVAL
Red	Black	several Ω, 0.1 Ω/m cable
Red	Green	several Ω
Red	Body	infinite (> 10^6 Ω)
Green	White	several Ω, 0.7 Ω/m cable
Green	Body	infinite (> 10^6 Ω)
Blank shield/ drain wire	Body	several Ω

6.4 Checks in the field

On-site field check is possible by comparison to a reference sensor, temporarily mounted side by side.

Hukseflux main recommendations for field checks are:

1) to compare to a new sensor
2) use high heat flux levels

7 Appendices

7.1 Example calculations

For Steel HII, a typical shell / mantle material, one might use (accuracy relative to the literature value within ± 2 % from 50 to 500 ° C):

λ = 51.508 - 0.0082T-0.000003 T^2 (Formula 7.1.1)

Formula 0.1 now becomes:

Φ = U (51.508 - 0.0082T - 0.000003 T^2) / (2,0651155788656 -0,0004301864802 T + 0,0000013193473 T^2) (Formula 7.1.2)

with Φ in W/m^2 and U in x 10^{-6} V

For Graphite Type EGFD one might use (accuracy relative to the literature value within ± 1 % from 50 to 500 ° C):

λ = 159.75-0.1607T+0.00007 T^2 (Formula 7.1.3)

Formula 0.1 now becomes:

Φ = U (159.75 - 0.1607 T + 0.00007 T^2) / (2,0651155788656 -0,0004301864802 T + 0,0000013193473 T^2) (Formula 7.1.4)

with Φ in W/m^2 and U in x 10^{-6} V

For Radex-Hue-T MgO bricks one might use (accuracy relative to the literature value within ± 10% from 200 to 1200 ° C):

λ = 11.17 – 0.006 T (Formula 7.1.5)

Formula 0.1 now becomes:

Φ = U (11.17 – 0.006T) / (2,0651155788656 -0,0004301864802 T + 0,0000013193473 T^2) (Formula 7.1.6)

with Φ in W/m^2 and U in x 10^{-6} V

For Radexcompact-S MgO bricks one might use (accuracy relative to the literature value within ± 10% from 200 to 1200 ° C):

λ = 9.86 – 0.047 T (Formula 7.1.7)

Formula 0.1 now becomes:

$$\Phi = U\,(9.86 - 0.047T) \,/\, (2{,}0651155788656 - 0{,}0004301864802\,T + 0{,}0000013193473\,T^2) \quad \text{(Formula 7.1.8)}$$

with Φ in W/m^2 and U in x 10^{-6} V

The overall heat flux measurement accuracy is typically somewhere between 4 and 11 %, mainly depending on the accuracy of λ. By contrast, as system based on individual temperature measurements will typically reach an accuracy of 20 %.

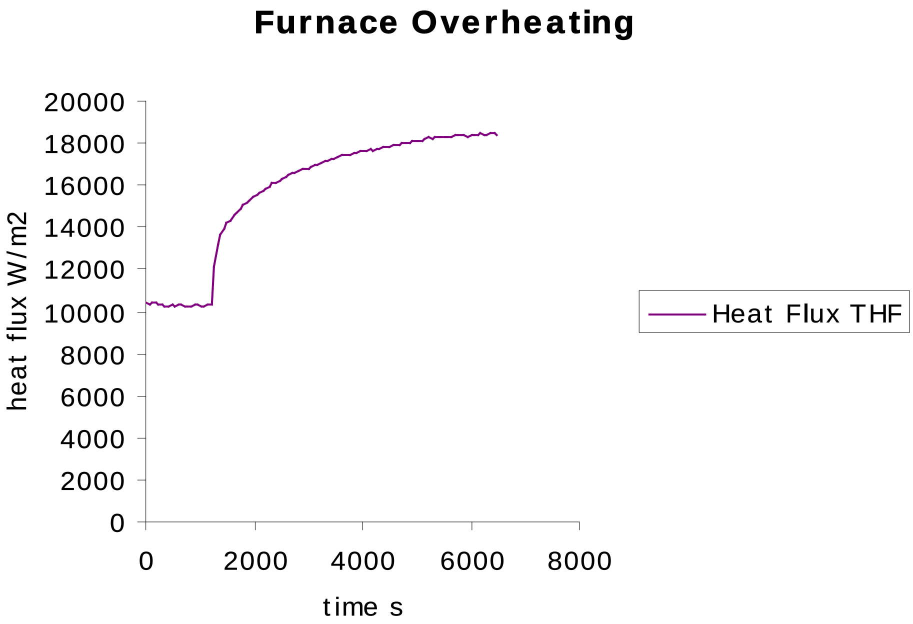
7.2 Analysis of iron furnaces

NF01 is a useful tool for distinguishing between various emergency situations.
It helps to provide a quick response.

This paragraph shows several examples of possible analysis of measurement data of NF01 when employed in an iron furnace.

Table 7.2.1 *Examples of furnace conditions. "0" is normal, "+" is increased, "++" is strongly increased. Column 1 showing various possible conditions: normal, cooling system malfunction, high heat development possibly caused by water in the furnace, disturbed thermal contact caused by cracks. Columns 2, 3 and 4 show resulting signals for temperature and heat flux in the shell and the graphite.*

CONDITION	SHELL TEMPERATURE	GRAPHITE TEMPERATURE	HEAT FLUX
normal operation	0	0	0
cooling system malfunction	++	+	0
furnace heat development	++	++	++
graphite cracking	0	++	0



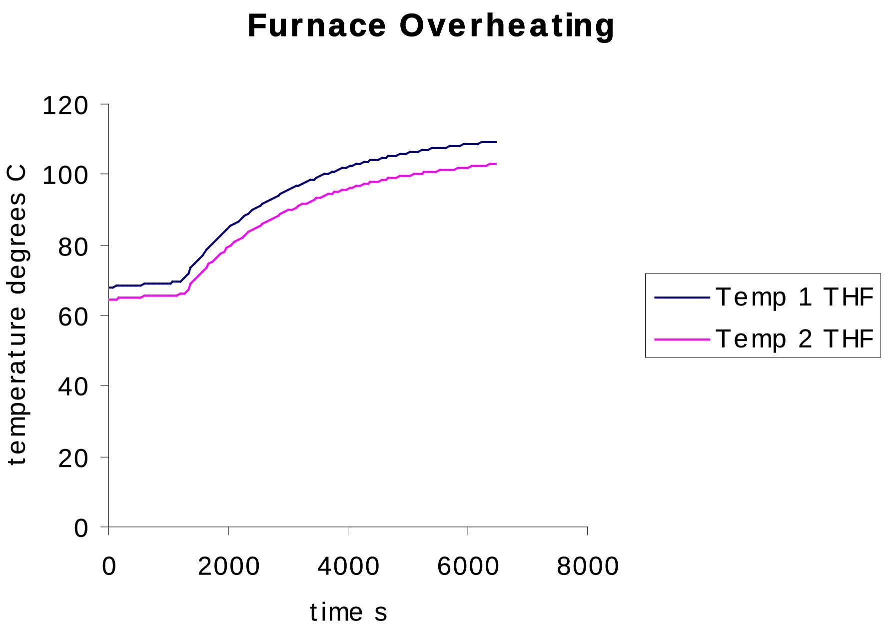
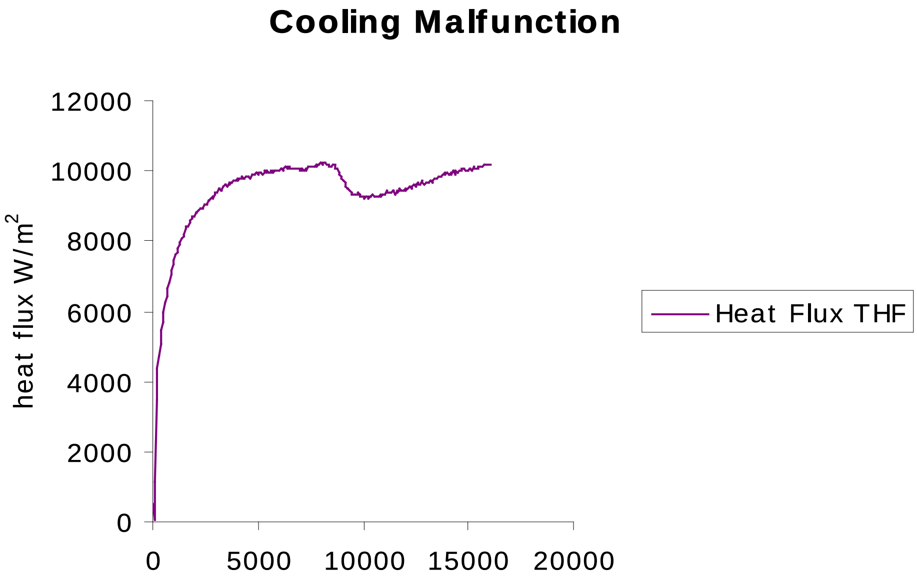


Figure 7.2.1 *Example 1: simulation of furnace overheating. Normal operation of the furnace until about 1000 s. Form then on the furnace starts overheating. In case of furnace overheating all temperatures as well as the heat flux rise. In this case the heat flux is increased by a factor 1.8.*



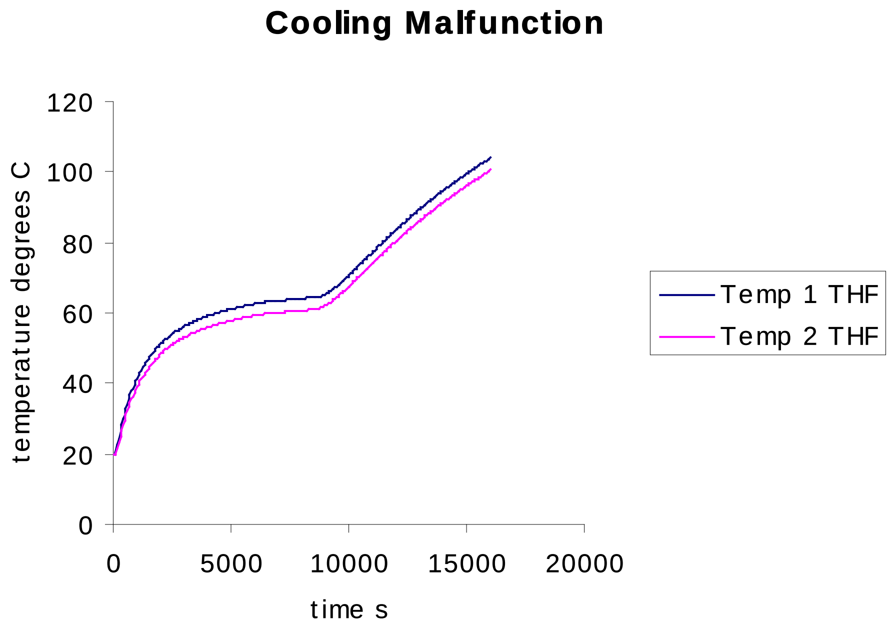


Figure 7.2.2 *Example 2: simulation of cooling malfunction. Around 8000 s after initial start-up of the furnace, the water cooling is stopped. The temperatures rise quickly but the heat flux, after a temporary dip caused by thermal loading, stays close to normal. It will eventually stabilise close to the original heat flux at a higher absolute temperature. Please note that the heat flux signal has been corrected for the temperature dependence of the thermal conductivity.*

7.3 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:	NF01
Product type:	Needle type heat flux and temperature sensor

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

Emission:	EN 61326-1: 2013
Immunity:	EN 61326-1: 2013

Eric HOEKSEMA
Director
Delft
March 01, 2016