INTERNATIONAL STANDARD

ISO 14934-1

First edition
2010-06-15

Fire tests — Calibration and use of heat flux meters —

Part 1:
General principles

Essais au feu — Étalonnage et utilisation des appareils de mesure du flux thermique —

Partie 1: Principes généraux

Reference number
ISO 14934-1:2010(E)

PDF disclaimer

This PDF file may contain embedded typefaces. In accordance with Adobe's licensing policy, this file may be printed or viewed but shall not be edited unless the typefaces which are embedded are licensed to and installed on the computer performing the editing. In downloading this file, parties accept therein the responsibility of not infringing Adobe's licensing policy. The ISO Central Secretariat accepts no liability in this area.

Adobe is a trademark of Adobe Systems Incorporated.

Details of the software products used to create this PDF file can be found in the General Info relative to the file; the PDF-creation parameters were optimized for printing. Every care has been taken to ensure that the file is suitable for use by ISO member bodies. In the unlikely event that a problem relating to it is found, please inform the Central Secretariat at the address given below.

COPYRIGHT PROTECTED DOCUMENT

© ISO 2010

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

Published in Switzerland

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 14934-1 was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 1, *Fire initiation and growth*.

This first edition of ISO 14934-1 cancels and replaces ISO/TS 14934-1:2002, which has been technically revised.

ISO 14934 consists of the following parts, under the general title *Fire tests — Calibration and use of heat flux meters*:

- *Part 1: General principles*
- *Part 2: Primary calibration methods*
- *Part 3: Secondary calibration method*
- *Part 4: Guidance on the use of heat flux meters in fire tests* [Technical Specification]

Introduction

In many fire test methods, the radiation level is specified and therefore, it is of great importance that the radiant heat flux be well defined and measured with sufficient accuracy. Radiant heat transfer is also the dominant mode of heat transfer in most real fires.

In practice, radiant heat flux is usually measured with so-called total heat flux meters of the Schmidt-Boelter (thermopile) or Gardon (foil) type. It is important to realize that such meters always register a combined heat flux from radiation and convection. It is also important to realize that the total heat flux meters register the heat flux to a cooled surface which is not the same level of heat flux that a non-cooled surface receives. Finally, the only heat transfer that is well defined is the incident radiant heat of the calibration situation in the black-body radiant sources used for primary calibration.

This part of ISO 14934 gives the terms and definitions intended for use with the other parts, namely ISO 14934-2 (three primary methods for calibration of heat flux meters), ISO 14934-3 (conduct of secondary calibration) and ISO/TS 14934-4 (construction and use of different types of heat flux meters).

Fire tests — Calibration and use of heat flux meters —

Part 1:
General principles

1 Scope

This part of ISO 14934 specifies the terms and definitions for the calibration and use of heat flux meters (see ISO 14934-2, ISO 14934-3 and ISO/TS 14934-4). It also describes the relationship between output voltage and total heat flux. It gives uncertainty components that are relevant for the calibration and use of heat flux meters (see Clause 7).

This part of ISO 14934 does not contain the methods for the calibration of heat flux meters, which are covered in ISO 14934-2 and ISO 14934-3.

2 Normative references

The following referenced documents are indispensable for the application of this document and for the other parts of ISO 14934. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 13943:2008, *Fire safety — Vocabulary*

ISO 14934-2, *Fire tests — Calibration and use of heat flux meters — Part 2: Primary calibration methods*

ISO 14934-3, *Fire tests — Calibration and use of heat flux meters — Part 3: Secondary calibration method*

ISO/TS 14934-4, *Fire tests — Calibration of heat flux meters — Part 4: Guidance on the use of heat flux meters in fire tests*

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

ISO/IEC Guide 99, *International vocabulary of metrology — Basic and general concepts and associated terms (VIM)*

ASTM E511, *Standard Test Method for Measuring Heat Flux Using a Copper-Constantan Circular Foil Heat-Flux Transducer*

ASTM E2683, *Standard Test Method for Measuring Heat Flux Using Flush-Mounted Insert Temperature-Gradient Gages*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13943, ISO/IEC Guide 98-3 and ISO/IEC Guide 99 and the following apply.

NOTE The definitions are listed as primary and secondary definitions. The secondary definitions are developed from the primary definitions. The definitions are listed according to the hierarchy of the concepts.

3.1 Primary definitions

3.1.1

radiation

emission or transfer of energy in the form of electromagnetic waves with the associated photons

NOTE See Reference [1].

3.1.2

heat

energy transferred from one body or system to another due to a difference in temperature

NOTE 1 See Reference [3].

NOTE 2 Heat is expressed in joules.

3.1.3

heat transfer

transfer of energy from one body or system to another as a result of a difference in temperature

EXAMPLE **Radiative heat transfer** (3.2.1), **convective heat transfer** (3.2.2) or conductive heat transfer.

NOTE 1 The bodies can be a gas, liquid, solid body, or some combination.

NOTE 2 Heat transfer is expressed in watts.

NOTE 3 Adapted from definition of ‘heat transfer’ contained in Reference [3].

3.1.4

convection

transfer of heat by movement of a fluid

[ISO 13943:2008, definition 4.54]

3.1.5

heat flux

amount of thermal energy emitted, transmitted or received per unit area and per unit time

NOTE 1 Heat flux for fire testing purposes is expressed in watts per square metre.

NOTE 2 Outside the fire testing field this definition is given as “heat flux density”.

NOTE 3 Adapted from ISO 13943:2008, definition 4.173.

3.1.6

radiosity

total of radiative heat flux emitted and radiative heat flux reflected leaving a surface when no radiative heat flux is transmitted

NOTE 1 See Reference [4].

NOTE 2 This definition is relevant to method 1 of ISO 14934-2.

NOTE 3 Radiosity is expressed in watts per square metre.

3.1.7
black-body radiation source

ideal thermal radiation source which completely absorbs all incident heat radiation, whatever wavelength and direction

NOTE 1 Adapted from ISO 80000-7:2008.

NOTE 2 A more physical definition of black body radiation source is given in ISO 13943.

3.1.8
irradiance

incident radiative heat flux arriving from all hemispherical directions

NOTE Irradiance is expressed in watts per square metre.

3.1.9
emissivity

ratio of the radiation emitted by a radiant source to the radiation that would be emitted by a **black-body radiation source** (3.1.7) at the same temperature

NOTE Emissivity is dimensionless.

[ISO 13943:2008, definition 4.75]

3.1.10
absorptivity

ratio of the absorbed radiant heat flux to the incident radiative heat flux

NOTE Absorptivity is dimensionless.

3.1.11
radiative intensity

radiative heat flux per unit solid angle leaving a source in a given direction

NOTE 1 Radiative intensity is expressed in watts per steradian.

NOTE 2 See Reference [5].

3.1.12
heat flux meter

instrument responding to incident radiative heat transfer, or convective heat transfer to a cooled surface, or both

3.1.13
radiometer

heat flux meter responding to incident radiative heat flux only

3.1.14
total hemispherical radiometer

radiometer equally sensitive to radiative intensity arriving from all directions above the sensing surface

3.1.15
total heat flux meter

heat flux meter responding to both incident radiative heat transfer and convective heat transfer to a cooled surface

NOTE The expression “heat flux meter” without the denotation “total” is typically used only when it is not specified whether the instrument is a radiometer or a total heat flux meter.

3.1.16

primary standard

standard that is designated or widely acknowledged as having the highest metrological qualities and whose value is accepted without reference to other standards of the same quantity

[ISO/IEC Guide 99]

3.1.17

secondary standard heat flux meter

heat flux meter with a calibration traceable to a primary standard, used only for calibration of working-standard heat flux meters

3.1.18

working-standard heat flux meter

heat flux meter calibrated by reference to a secondary standard for subsequent use during the course of fire tests

3.1.19

sensing surface

surface of the heat flux meter that detects the irradiance

3.1.20

sensitivity

ratio of the output voltage to the measured quantity

3.1.21

Stefan-Boltzmann constant

σ

constant of proportionality in the expression in the Stefan-Boltzmann law for calculating the radiative heat flux from the absolute temperature

NOTE 1 This constant is equal to $5{,}670\,400 \times 10^{-8}$ watts per square metre and per kelvin to the fourth power.

NOTE 2 See Reference [2].

3.2 Secondary definitions

3.2.1

radiative heat transfer

heat transfer by radiation

NOTE Radiative heat transfer is expressed in watts.

3.2.2

convective heat transfer

transfer of heat to a surface from a surrounding fluid by convection (3.1.4)

NOTE The amount of heat transfer depends on the temperature difference between the fluid and the surface, the fluid properties and the fluid velocity and direction.

3.2.3

total heat transfer

sum of the radiant heat transfer and the convective heat transfer

3.2.4

incident heat radiation

incoming radiative heat

3.2.5
absorbed heat radiation
radiative heat absorbed by a surface

3.2.6
emitted heat radiation
radiant heat emitted from a surface

3.2.7
net heat radiation
difference between the absorbed heat radiation and the emitted heat radiation

3.2.8
radiative heat flux
heat flux by radiative heat transfer

NOTE 1 The adjectives radiative and radiant are interchangeable and both terms are used in ISO 14934 (all parts).

NOTE 2 **Radiosity** (3.1.6) is a similar but not fully synonymous expression.

NOTE 3 Radiant or radiative heat flux is expressed in watts per square metre.

3.2.9
convective heat flux
heat flux by convective heat transfer

NOTE Convective heat flux is expressed in watts per square metre.

3.2.10
total heat flux
sum of net radiant heat flux and convective heat flux

NOTE Total heat flux is expressed in watts per square metre.

4 Symbols

$\dot{q}''_{\text{tot}}$	total heat flux to the sensing surface
$\dot{q}''_{\text{rad}}$	heat radiation absorbed by the sensing surface
$\dot{q}''_{\text{emi}}$	emitted heat radiation from the sensing surface
$\dot{q}''_{\text{con}}$	convective heat transfer to the sensing surface
T_∞	absolute ambient temperature
ε	absorptivity of the sensing surface; the absorptivity and the emissivity of the sensing surface are assumed equal
I_{rad}	incident heat radiation as defined by the calibration method (see Clause 7); the view angle dependence for the method is included in the value
T_W	absolute temperature of the cooling water, which is assumed to also represent the temperature of the heat flux meter
A_0, A_1, A_2	constants to be determined by the calibration procedure in a best-fit procedure as described in Clause 7

U_{out}	output voltage signal
s	standard deviation
ν	number of degrees of freedom in the regression line model
n	number of radiation levels
$\hat{y}_i$	value from the regression model
y_i	measured value for the level x_i

5 Principles

5.1 Principles of calibration

Heat flux meters for daily use in fire testing (working standard heat flux meters) may be calibrated according to either a primary calibration method or a secondary calibration method.

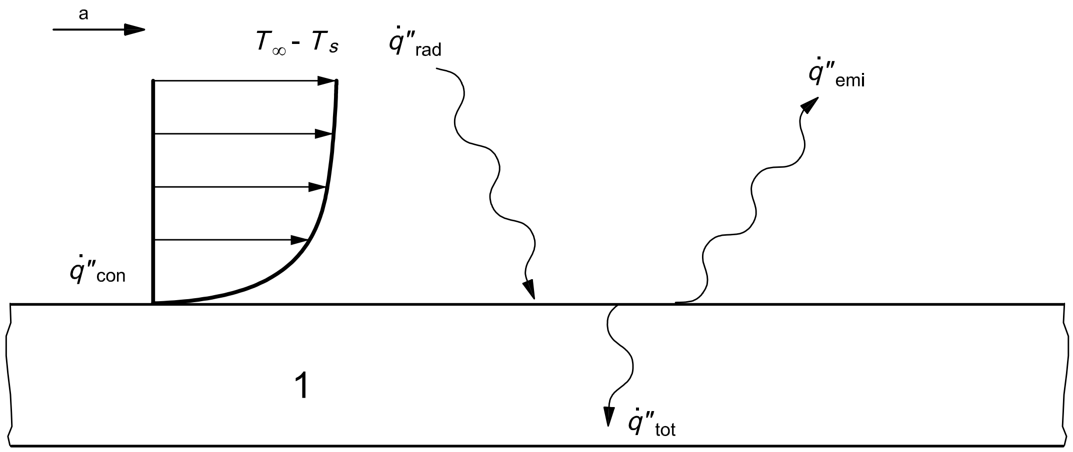
Primary calibration shall be performed according to one of the three primary methods described in ISO 14934-2. Secondary calibration shall be performed according to the principles described in ISO 14934-3. When the secondary calibration is performed as a transfer calibration, the secondary-standard heat flux meter shall be primary calibrated.

5.2 Principles of measuring radiant heat flux

Assuming the emissivity/absorptivity of the sensing surface equals unity, the total heat flux received, $\dot{q}''_{\mathrm{tot}}$, is given by Equation (1):

$$\dot{q}''_{\mathrm{tot}} = \dot{q}''_{\mathrm{rad}} - \dot{q}''_{\mathrm{emi}} + \dot{q}''_{\mathrm{con}} \qquad (1)$$

The heat balance of Equation (1) is illustrated in Figure 1.



Key

1 sensing surface

[a] Direction of airflow.

Figure 1 — The heat balance at the sensing surface

The heat radiation that is absorbed by the heat flux meter depends on the absorptivity of the sensing surface, given by Equation (2):

$$\dot{q}''_{\mathrm{rad}} = \varepsilon \times I_{\mathrm{rad}} \tag{2}$$

The emitted heat radiation from the sensing surface, $\dot{q}''_{\mathrm{emi}}$, is given by Equation (3):

$$\dot{q}''_{\mathrm{emi}} = \varepsilon \times \sigma T_{\mathrm{s}}^{4} \tag{3}$$

where the surface temperature, T_{s}, is assumed to be equal to the water temperature, T_{w}.

The convective heat transfer, $\dot{q}''_{\mathrm{con}}$, is specific for the calibration method and for the application at use. Thus, the convective heat transfer depends on the configuration at the calibration or use situation. The temperatures of the ambient air, as well as the velocity of the air over the sensing surface, play important roles. Also, the temperature of the cooling water influences the convective heat transfer.

The total heat flux to the heat flux meter, $\dot{q}''_{\mathrm{tot}}$, creates a local temperature difference. The output voltage signal of the meter depends on this temperature difference. The sensitivity of heat flux meters is primarily determined by the physical composition of the heat flux meter itself. The combined properties of the absorber, surrounding geometry (limiting the field of view), window and foil/thermopile result in a certain output at a certain level of incident heat radiation.

The total heat flux to the heat flux meter, $\dot{q}''_{\mathrm{tot}}$, may be assumed to be a second-degree polynomial of the output voltage signal, as given by Equation (4):

$$\dot{q}''_{\mathrm{tot}} = A_0 + A_1 U_{\mathrm{out}} + A_2 U_{\mathrm{out}}^{2} \tag{4}$$

However, normally the second degree term, A_2, is small. Thus, a linear relation is obtained where the constant term, A_0, depends on the cooling water temperature.

6 Description, selection and use of heat flux meters

The different types of heat flux meters available for use in fire tests shall be as described in ISO/TS 14934-4, ASTM E511 and ASTM E2683. ISO/TS 14934-4 also contains guidance on the selection of type and design of heat flux meter for the purpose concerned. ISO/TS 14934-4 gives advice on the use of heat flux meters in different situations as well.

Either a total hemispherical radiometer or a total heat flux meter may be used to measure the radiant flux during a fire test.

Although the use of total hemispherical radiometers is not widespread, their use in daily measurement or during calibration in fire test methods has the advantage of requiring no correction for convective effects to the measured radiant heat flux. Only the radiant heat flux is measured and a total hemispherical radiometer may be used in any fire test method without the need to apply a correction for any convective heat transfer. Caution is recommended to ensure that the angular response of the radiometer has near-true cosine dependence.

During calibration of a total heat flux meter, all measures should be taken to reduce the convective contribution. In addition, an assessment of the amount of remaining convective contribution should be included in the uncertainty of the incident radiant flux for the calibration or measurement. Documented characterization of the convective component using additional measurements (e.g. sensing element temperature, local velocities and ambient gas temperatures near the sensing element) and modelling can allow the isolation of the radiant component, leading to reduced uncertainty in measurements. Total heat flux meters respond to any heat that is transferred to or from the sensing surface, and cannot distinguish between radiant or convective components of heat transfer. Hence, other means are necessary to quantify their relative importance.

However, it might not be necessary to measure the sensitivity of the meter to convection for every single specimen of heat flux meter. It is possible that corrections can be established for each separate type of meter for use in a particular calibration or fire test method. Thus, the output signal of a meter to total heat flux can be corrected to apply to only the radiant heat flux for every total heat flux meter used in that specific method.

7 Uncertainty analysis

7.1 Uncertainty sources in primary calibration

7.1.1 The following sources are included in the basic uncertainty components in the uncertainty budget of primary calibration in accordance with ISO 14934-2:

a) temperature of black-body radiant source;

b) emissivity of black-body surfaces;

c) apparent emissivity in black-body;

d) heat transfer model of the specific calibration method, including dimensions typical of the method;

e) output signal of heat flux meter.

7.1.2 In addition to the sources listed in 7.1.1, there are some uncertainty components that are specific to the method of calibration. These are uncertainties from:

a) pressure output reading (method 1);

b) convection during calibration (methods 2 and 3);

c) temperature of areas other than the black-body itself (method 2);

d) reference standard radiometer (method 3).

Round-robin results should also be taken into account.

ISO 14934-2 gives the number of levels for performing a primary calibration of a heat flux meter. The radiation levels chosen for the calibration can be either evenly distributed over the full range or more concentrated in a range of particular interest.

7.2 Uncertainty sources in secondary calibration

If secondary calibration in accordance with ISO 14934-3 is conducted as a transfer calibration, the uncertainty from the primary calibration is the main uncertainty component. In addition, the following sources are included in the basic uncertainty components in the uncertainty budget of secondary calibration:

a) convection during calibration;

b) temperature of heat source;

c) temperature of surrounding surfaces;

d) alignment of heat flux meter and heat source (including distance from source);

e) heat flux meter reading.

7.3 Uncertainty sources in making a regression of the calibration results

The number of radiation levels used for calibration influences the uncertainty in the regression of the calibration. When a linear regression has been performed, the standard deviation is calculated either by means of the computer program used for the regression or by Equation (5):

$$s^2 = \frac{1}{\nu} \sum_{i=1}^{n} (\hat{y}_i - y_i)^2 \tag{5}$$

The number of degrees of freedom, ν, equals the number of radiation levels subtracted by the number of parameters set in the regression, i.e. two for linear regression. The uncertainty for the regression curve is then calculated as the standard deviation times a coverage factor in order to get a 95 % confidence interval. If the degree of freedom is small, i.e. less than 10, the coverage factor shall be taken from the t-distribution.

To get the total expanded uncertainty for the heat flux measurement, the uncertainty contribution from the regression should be added to the uncertainty from the method in accordance with instructions given in ISO/IEC Guide 98-3. Examples of how the size of the uncertainty of the regression depends on the linearity of the heat flux meter are given in Annex B.

7.4 Uncertainty sources in using a heat flux meter

When using a heat flux meter, the convection can be different compared to the calibration situation. The contribution to the heat transfer by convection depends mainly on the temperature difference between the surrounding gases and the sensing surface and on the velocity of the surrounding gases. However, it also depends on the size and shape of the heat flux meter, its orientation and its temperature level, which is near the cooling water temperature. In many practical situations in fire testing, the contribution due to convection to the sensing surface of the instrument can be as high as 25 % of the radiant heat flux. The convective heat transfer can be either a positive or a negative term in Equation (1). Thus, it is always necessary to determine and be aware of this factor. The convection component of the heat flux shall be considered as an uncertainty component in the combined expanded uncertainty for the use of the heat flux meter.

The temperature of surrounding surfaces also influences the reading of the sensing surface. If the surfaces are hotter than the sensing surface, additional radiation will be received by the sensing surface. If the surrounding surfaces are colder than the sensing surface, this surface will emit radiation to the surrounding surfaces.

Annex A
(informative)

Comparison of calibration methods

Comparison of different calibration methods has been conducted in two activities within the FORUM for International Cooperation in Fire Research (see Reference [6]). In the two comparisons, a Gardon and a Schmidt-Boelter heat flux meter were used. The work commenced in 2000 when ISO 14934 (all parts) was under preparation by TC 92/SC 1/WG 10. Therefore, many of the calibration methods used in that comparison were not according to the procedures described in ISO 14934 (all parts). A variation of 8 % to 9 % of the averaged full-scale reading of the heat flux meters used in the first comparison was recorded. In the second comparison, the variation was 17 % to 21 % of the averaged full-scale reading. These results are reported in Chapter 4.4 (Comparisons based on predicted full-scale gauge responses) of the report.

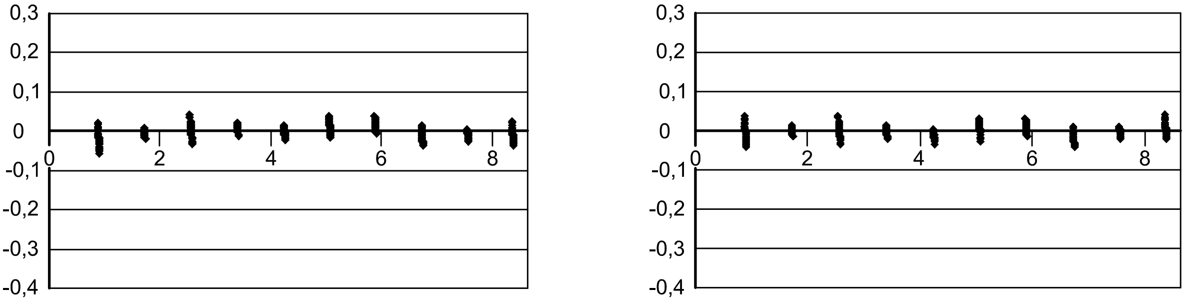
In the first comparison, all three methods that later became the primary methods of ISO 14934-2 were used. The following is a summary of the results of these methods: The average heat flux at 10 mV (referred to as full-scale reading in the report) and the variation (2σ) of the Gardon heat flux meter was in the primary methods $(89{,}2 \pm 4{,}9)$ kW/m^2. That corresponds to ±5,5 % of the average full-scale reading for these three methods. For the Schmidt-Boelter heat flux meter, the corresponding result in the primary methods was $(119{,}7 \pm 4{,}3)$ kW/m^2, which corresponds to ±3,6 % of the average full-scale reading.

Annex B
(informative)

Uncertainty sources in connection with regression of the calibration results

When a regression line is drawn based on the points from the radiation levels used for the calibration, the quality of the regression line depends on how well the points fit the regression line model. The quality of the regression line can easily be studied using residuals. Residuals are the differences between the observed values and the corresponding values that are predicted by the model and, therefore, they represent the variance that is not explained by the model. The better the fit of the model, the smaller the values of the residuals (see Reference [7]).

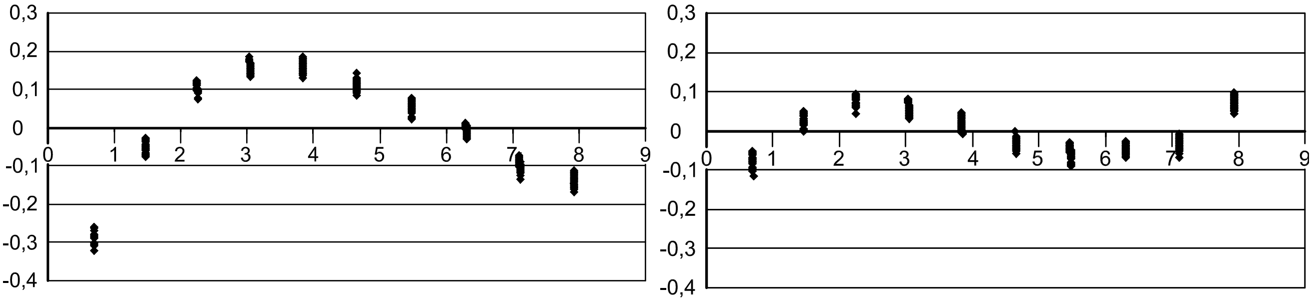
Figure B.1 is an example of a heat flux meter with a sensitivity which is linear over the whole calibration range. Figure B.2 is an example of a heat flux meter with a non-linear sensitivity.



a) Residuals — linear **b) Residuals — polynomial**

NOTE The range of the calibration was 1,5 kW/m^2 to 15 kW/m^2.

Figure B.1 — Residuals from linear and polynomial (parabolic) regression lines of a heat flux meter with linear sensitivity



a) Residuals — linear **b) Residuals — polynomial**

NOTE The range of the calibration was 5 kW/m^2 to 50 kW/m^2.

Figure B.2 — Residuals from linear and polynomial (parabolic) regression lines of a heat flux meter with non-linear sensitivity

By using Equation (5), the uncertainty contribution from the regression line was calculated. For the case shown in Figure B.1, the uncertainty contribution from the regression line was 0,03 kW/m^2. This value represents 2 % of the heat flux level at the lowest level of calibration (1,5 kW/m^2). The parabolic regression line for the case with the non-linear heat flux meter shown in Figure B.2 gives an uncertainty contribution of 0,15 kW/m^2 (3 % of 5 kW/m^2), while the linear regression line gives an uncertainty contribution of 0,36 kW/m^2 (7,2 % of 5 kW/m^2).

To get the total expanded uncertainty for the heat flux measurement, the uncertainty contribution from the regression should be added to the uncertainty from the method according to instructions given in ISO/IEC Guide 98-3.

Bibliography

[1] ISO 80000-7:2008, *Quantities and units — Part 7: Light*

[2] IEC 60500 (IEV 845), *International Vocabulary — Lighting*

[3] *Concise Science Dictionary*, 4th ed., Oxford University Press, Oxford, 1999

[4] INCROPERA, F.P., *Fundamentals of heat and mass transfer*. Wiley, 6th ed., 2007

[5] MODEST, M.F., *Radiative Heat Transfer*. 2nd ed., Academic Press, 2003

[6] PITTS, W.M., A. MURTHY, V., DE RIS, J.L., FILTZ, J.R., NYGÅRD, K., SMITH, D. and WETTERLUND, I., *Round robin study of total heat flux gauge calibration at fire laboratories*. National Institute of Standards and Technology Special Publication 1031, Gaithersburg, MD, USA, 2004

[7] StatSoft electronic statistics textbook, available at: http://www.statsoft.com/textbook/glosfra.html

ICS 13.220.40; 13.220.50

Price based on 13 pages