Thermal performance of building products and components — Specific criteria for the assessment of laboratories measuring heat transfer properties —

Part 5: Measurements by pipe test methods

The European Standard EN 1946-5:2000 has the status of a British Standard

ICS 91.100.01; 91.120.10

National foreword

This British Standard is the official English language version of EN 1946-5:2000.

The UK participation in its preparation was entrusted by Technical Committee RHE/9, Thermal insulating materials, to Subcommittee RHE/9/2, Thermal performance of insulating materials, which has the responsibility to:

— aid enquirers to understand the text;

— present to the responsible European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;

— monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this subcommittee can be obtained on request to its secretary.

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the BSI Standards Catalogue under the section entitled “International Standards Correspondence Index”, or by using the “Find” facility of the BSI Standards Electronic Catalogue.

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Thermal performance of building products and components - Specific criteria for the assessment of laboratories measuring heat transfer properties - Part 5: Measurements by pipe test methods

Performance thermique des produits et composants pour le bâtiment - Critères particuliers pour l'évaluation des laboratoires mesurant les propriétés de transmission thermique - Partie 5: Mesurage selon les méthodes d'essai des conduites

Wärmtechnisches Verhalten von Bauprodukten und Bauteilen - Technische Kriterien von Begutachtung von Laboratorien bei der Durchführung der Messungen von Wärmeübertragungseigenschaften - Teil 5: Messungen nach dem Rohrprüfgerät- Verfahren

This European Standard was approved by CEN on 10 April 2000.

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Contents

Foreword

This European Standard has been prepared by Technical Committee CEN/TC 89, Thermal performance of buildings and building components, the Secretariat of which is held by SIS.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by November 2000, and conflicting national standards shall be withdrawn at the latest by November 2000.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

This European Standard is divided into parts. The first part covers common criteria applicable to all heat transfer property measurements; each subsequent part covers the specific technical criteria applicable to each heat transfer property measurement method described in appropriate standards.

The following parts have been developed:

- Part 1: Common criteria;
- Part 2: Measurements by the guarded hot plate method;
- Part 3: Measurements by the heat flow meter method;
- Part 4: Measurements by hot box methods;
- Part 5: Measurements by pipe test methods.

Annex A of this European Standard is normative, the Annexes B and C are informative.

1 Scope

Part 5 of this standard provides specific technical criteria for the assessment of laboratories to undertake steady-state heat transfer property measurements on circular pipe insulation according to EN ISO 8497:1994.

It complements the common criteria in Part 1. Guidance is given on the organization and contents of the equipment manual, the calibration and maintenance files and the measurement procedure document.

It provides information on mandatory equipment performance specifications, on equipment description and on calculations for the equipment design and error analysis based on both EN ISO 8497:1994 on circular pipe apparatus and on Part 2 of this standard on the assessment of guarded hot plate apparatus.

It gives information on experimental procedures suitable for the assessment of equipment accuracy, based on both EN ISO 8497:1994 on circular pipe apparatus and on Part 2 of this standard on the assessment of guarded hot plate apparatus.

2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

EN 1946-1:1999, *Thermal performance of building products and components - Specific criteria for the assessment of laboratories measuring heat transfer properties - Part 1: Common criteria*

EN 1946-2:1999, *Thermal performance of building products and components - Specific criteria for the assessment of laboratories measuring heat transfer properties - Part 2: Measurements by guarded hot plate method*

EN 12667[1)], *Thermal performance of building materials and products - Determination of thermal resistance by means of guarded hot plate and heat flow meter methods - Products of high and medium thermal resistance*

EN ISO 7345, *Thermal insulation - Physical quantities and definitions (ISO 7345:1987)*

EN ISO 8497:1994, *Thermal insulation - Determination of steady-state thermal transmission properties of thermal insulation for circular pipes (ISO 8497:1994)*

prEN 13467:1999, *Thermal insulating products for building equipment and industrial installations - Determination of dimensions, squareness and linearity of preformed pipe insulation*

[1)] To be published

3 Definitions

For the purposes of this part of the standard, the terms and definitions given in Part 1 of this standard, EN ISO 7345 and EN ISO 8497:1994 apply.

4 Equipment manual

4.1 General

The equipment manual shall provide the information specified in 5.2.2 to 5.2.5 of Part 1 of this standard and the information specified in this clause.

NOTE: Information common to more than one piece of equipment need not be duplicated, e.g. the principle, details of the design and operation of two pieces of equipment built to a common design.

Annex A gives all limiting values indicated in EN ISO 8497:1994 for equipment performance and testing conditions. This annex shall be used as a check list during the assessment process by the parties concerned to ensure compliance with all EN ISO 8497:1994 requirements.

4.2 Equipment performance specifications

The upper and lower limits of the relevant tested properties and testing conditions, including possible interactions between them, shall be specified:

- minimum and maximum external diameter of the specimen;
- minimum and maximum specimen thermal resistance;
- minimum and maximum temperature difference across the specimen;
- minimum cold side temperature;
- maximum hot side temperature;
- surrounding environment (temperature, relative humidity) at the ends of the specimen during the test, if required.

4.3 Equipment description

The following information shall be documented and shall be available for examination during the assessment:

- principle of operation (see clause 1 of EN ISO 8497:1994);
- type of apparatus: guarded-end apparatus, see 7.3 of EN ISO 8497:1994, or calibrated/calculated-end apparatus, see 7.4 of EN ISO 8497:1994;
- principal dimensions of apparatus, in particular length of test pipe centre, test pipe guard, test pipe diameter and gap width;
- simple diagrams illustrating the design of the equipment with special attention to the gap design (see clause 7.3 of EN ISO 8497:1994), cap design (if applicable, see 7.4 of EN ISO 8497:1994), jacket or added insulation (if applicable see 7.11 of EN ISO 8497:1994);
- position, connections and numbering of temperature sensors (see 7.6 of EN ISO 8497:1994);
- ambient control and main ancillary equipment (see 7.8 to 7.10 of EN ISO 8497:1994);
- details of data acquisition system and related computer programs for data analysis.

To avoid duplication, reference may be made to manuals supplied by the instrument manufacturers or to relevant clauses of EN ISO 8497:1994.

4.4 Equipment design and error analysis

4.4.1 General

With reference to the performance specification given in 4.2, details shall be given in the equipment manual on the design guidelines followed, and the error analysis.

Some guidelines on error analysis are given in this subclause; more specific information on some errors is supplied in Annex B, while error calculations are supplied in Annex C for some typical cases. For equipment having characteristics exactly as indicated in this subclause, or design details as indicated in Annex C, no further calculations are needed. In other circumstances similar calculations can be performed by analogy.

4.4.2 Axial heat flow rate and maximum specimen thickness

4.4.2.1 General

The axial heat flow rate from the test section to the guard sections of the specimen affects the maximum specimen thickness. The axial heat flow rate shall not exceed that permitted by 9.5.2.2 of EN ISO 8497:1994 (1 % of heat flow rate of the test section, i.e. the end heat loss error shall be less than 1 %).

4.4.2.2 Guarded-end apparatus

Table 1 shows for some apparatus having an overall pipe length of 1000 mm and other dimensions as given in the table, the maximum allowed specimen thickness according to the equations proposed in Annex B. Those expressions are based on 2.2.1 of ISO 8302:1991, see [1] in the Bibliography, when there is no end insulation and when the end temperature ratio, e, is 0; e is defined as $(T_e - T_2)/(T_1 - T_2)$, where T_1 and T_2 are respectively the temperatures of the hot and cold surfaces of the specimen, and T_e is the temperature at the ends of the specimen, assumed to be uniform.

NOTE: The end heat loss error is zero for homogeneous isotropic specimens when e is close to 0,5; the absolute value of the edge heat loss error increases almost symmetrically when e deviates on either side from 0,5. In the range $0 \le e \le 1$, this error is maximum for for $e = 0$.

EXAMPLE: A temperature of the specimen ends of 50 °C, a temperature of the specimen cold side of 50 °C (so that the temperature difference between the ends and the cold side of the specimen is 0 °C) and a temperature of the specimen hot side of 150 °C (so that the temperature difference between the hot and cold side of the specimen is 100 °C) corresponds to $e = 0$. If the temperature of the specimen ends were of 60 °C, then it would be $e = 0,1$.

The data of the table can be applied to apparatus and specimens having all the dimensions multiplied by the same factor. Interpolation is allowed.

EXAMPLE: By considering a multiplying factor of 2,4, an apparatus has an overall pipe length of 1 000 × 2,4 = 2 400 mm, the pipe centre length of 800 × 2,4 = 1 920 mm and a pipe diameter of 100 × 2,4 = 240 mm. The resulting maximum specimen thickness, see the third line of Table 1, is 70 × 2,4 = 170 mm (rounded to two significant figures).

Table 1 - Maximum allowed specimen thickness for guarded end apparatus

Dimensions in millimetres

Overall pipe length	Pipe centre length	Pipe guard width	Pipe diameter	Maximum specimen thickness
1 000	400	300	100	125
1 000	700	150	100	90
1 000	800	100	100	70
1 000	400	300	50	110
1 000	700	150	50	75
1 000	800	100	50	60
1 000	400	300	25	90
1 000	700	150	25	65
1 000	800	100	25	50
1 000	400	300	12,5	80
1 000	700	150	12,5	55
1 000	800	100	12,5	45
1 000	400	300	6	65
1 000	700	150	6	45
1 000	800	100	6	35

Larger specimen thicknesses can be used for some specimens if insulation or temperature control is used at the ends of the specimen, or if auxiliary guards are installed.

When the maximum specimen thickness to be specified according to 4.2 exceeds the appropriate value given in Table 1, the axial heat flow rate shall be calculated. If, according to these calculations, the axial heat flow rate exceeds the values permitted by EN ISO 8497:1994, the performance check data shall be examined and, if no experimental evidence exists to substantiate the claimed maximum specimen thickness, the maximum specimen thickness to be specified according to 4.2 shall be reduced.

4.4.2.3 Calibrated or calculated-end type apparatus

When corrections are applied for axial heat flow rate either through the calibration procedure indicated in 10.1 of EN ISO 8497:1994 or through the calculations indicated in 10.2 of EN ISO 8497:1994, the correction should not be larger than 3 % of the heat flow rate supplied to the specimen by the test pipe centre.

NOTE: This limit implies that the accuracy of the correction is 33 % or better. This figure is intended to make allowance for a similar difference between the thermal conductivity of the end cap and that of the specimen. Larger corrections are acceptable, provided that the uncertainty in the corrected heat flow rate supplied to the specimen by the test pipe centre is within the 1 % required by 9.5.2.2 of EN ISO 8497:1994.

4.4.3 Maximum gap width and minimum specimen thickness

The gap width, g, in guarded-end apparatus should be less than 1 % of the length of the test pipe centre.

NOTE: Considering that the test section length, L, is defined (in 9.1.1 of EN ISO 8497:1994) as the distance from gap centre to gap centre, the above requirement keeps within 1 % the uncertainty in the definition of the area through which the heat flow at the rate Φ passes, supplied to the specimen by the test pipe centre, even when the specimen thickness is comparable or less than the gap width. In this situation the area through which the heat flow rate supplied by the test pipe centre passes approaches that of the test pipe centre itself from gap edge to gap edge. When, on the other hand, the specimen thickness is far larger than the gap width (e.g. 10 times) the border of this area is defined by the lines passing through the centre of the gaps, i.e. the uncertainty on the test section, L, is in any case less than the gap width, g.

The minimum specimen thickness shall also be checked against the expected air gap between the specimen and the apparatus, see 4.4.9.

4.4.4 Imbalance error

The imbalance heat flow rate, Φ_g, through both the specimen and the apparatus (both gaps) shall be less than 1 % of the heat flow rate, Φ, supplied to the specimen by the test pipe centre (according to 9.4 of EN ISO 8497:1994).

The imbalance heat flow rate Φ_g can be expressed as follows (according to 4.4.4 of Part 2 of this standard):

$$\Phi_g = (\Phi_o + \lambda c) \Delta T_g \qquad (1)$$

where Φ_o, representing the heat flow rate for a 1 K gap imbalance through the apparatus itself, is the sum of:

- Φ_a through the air in the gap;
- Φ_r by radiation through the gap;
- Φ_m through the mechanical connections through the gap;
- Φ_c through copper wires;
- Φ_w through metal wires (excluding copper)

and λc is the heat flow rate through the specimen (both gaps) due to a 1 K gap imbalance with c expressed by the following equation:

$$c = (2\, d_o) \ln (4/(1 - \exp(- \pi\, g/d)) \qquad (2)$$

In equation (2) d_o is the outer diameter of the test pipe, g is the gap width and d is the maximum expected specimen thickness.

ΔT_g shall be such that Φ_g in equation (1) is less than 1 % of the heat flow rate Φ.

NOTE: To calculate the components of Φ_O, the elementary equations of heat transfer through a plane layer can be used.

The calculation of Φ_g changes according to the gap design and is the most critical part of the evaluation of pipe test apparatus accuracy. Some example calculations are given in Annex C.

Because the balancing thermopile detects a temperature difference that does not correspond exactly with the actual temperature imbalance through the pipe surfaces facing the gaps and in contact with the specimen, the maximum acceptable value for ΔT_g shall be larger than the uncertainty in the imbalance detection. Detailed information on the imbalance detection through the gap is given in 2.1.1.5 of ISO 8302:1991 on the guarded hot plate apparatus, see [1] in the Bibliography. Those considerations are equally applicable to the pipe test apparatus.

When the balancing thermopile is placed directly within the metal pipe, see the equivalent situation described by Figure D.3 a) of EN 12667 on the guarded hot plate apparatus, the density of heat flow rate crossing the gaps during the tests shall be evaluated and the corresponding temperature drop through the metal pipe computed. If this temperature difference is less than ΔT_g, the gap design is acceptable without further checks, otherwise the tolerances for the positions of thermopile junctions within the metal plates shall be checked to ensure that the uncertainty in the temperature imbalance detection is less than ΔT_g.

When the balancing thermopile is embedded in plastic sheets, either placed between the metal pipe and the heaters, or between the metal pipe and the specimen, the effect of the resistances between the metal pipe and the thermopile junctions due to the plastic sheets, and possible air pockets, shall be evaluated as a temperature difference resulting from the product of the relevant thermal resistance and the density of heat flow rate passing through it.

The electrical instrumentation used for the imbalance detection shall be capable of detecting voltages less than ΔT_g multiplied by the number of elements of the balancing thermopile and by the thermoelectric power of each element. The electrical balance maintained during the tests shall therefore be better than the voltage computed in this way. If this requirement is not met, the measured data of the performance check, see the fourth dash of 4.5, shall be verified and if the sensitivity of the instrumentation for the imbalance detection is still not satisfactory, better instrumentation shall be chosen or the balancing thermopile design shall be reviewed. Particular care shall also be taken to ascertain that the quality of the electrical connections and the switches (with reference, in particular, to thermal electromotive forces) is compatible with the level of imbalance to be detected.

4.4.5 Error in measured electrical power

The uncertainty in the measurement of electrical power shall be within 0,5 %, to comply with clause 7.9 of EN ISO 8497:1994.

4.4.6 Error in the definition of the area of the test section

The area of the test section is defined as the area enclosed by the line defining the centre of the gaps (see 9.1.1 of EN ISO 8497:1994). This area is not equal in all testing conditions to the actual area of the specimen crossed by the heat flow rate supplied by the test pipe centre, see 4.4.3; to this uncertainty shall be added the uncertainty in the measurement of the dimensions of the apparatus. An uncertainty due to mechanical tolerances in the measurement of the centre-gap to centre-gap distance up to 0,1 % can be accepted.

4.4.7 Error in the temperature difference

Whatever heat transfer property is measured with the pipe apparatus, the difference between the pipe surface temperature T_o (see 7.5 of EN ISO 8497:1994) and the temperature T_2 of the outside surface of the specimen (see 8.6 of EN ISO 8497:1994) shall be measured. The total error in the temperature difference (T_o - T_2) is made up as follows:

- calibration of thermocouples (or other temperature sensors): typically less than 0,4 %, see NOTE 1;
- accuracy of measuring instruments: typically less than 0,2 %;
- temperature uniformity of the test pipe centre: typically better than 0,5 K;
- temperature uniformity of the external surface of the specimen: typically 0,7 K, see NOTE 4; for this temperature uniformity see also 7.11 of EN ISO 8497:1994;
- temperature fluctuations of the ambient air: ± 1 K or ± 1 % of the temperature difference between the test pipe and the ambient, according to 9.2 of EN ISO 8497:1994.

NOTE 1: When special grade thermocouples (see 4.4.7 of Part 2 of this standard) mounted differentially are used, as in Figure D.5 of EN 12667, and no additional wire connections between the junctions are made, no calibration is required. For example an uncertainty of 0,4 % at room temperature can be achieved using type T thermocouples.

NOTE 2: The absence of additional wire connections between two thermocouple junctions (or an extremely high quality of the fabrication of these junctions) and keeping them as isothermal as possible during the tests, are more important than the thermocouple calibration itself. Bad thermocouple connections can induce errors that will change for different testing conditions, so reducing the accuracy of the calibrations.

NOTE 3: The uncertainty in the definition of the point where the surface temperature of the pipe is measured can be assumed to cause an error in the temperature reading not greater than the temperature drop through the thickness of the metal part of the pipe apparatus when thermocouples are mounted in grooves in this part. When thermocouples are mounted in thin sheets, the uncertainty for the surface temperature of the pipe becomes critical and can be assumed to be equal to the temperature drop through a layer of sheet of thickness equal to the diameter of the thermocouple junction. According to 7.6 of EN ISO 8497:1994, the maximum allowed thermocouple diameters when measuring metallic or non-metallic surface temperatures are 0,63 mm and 0,4 mm, respectively.

NOTE 4: The temperature non-uniformity on the external surface of the specimen is partly due to the temperature non-uniformity of the air surrounding it and to the local non-uniformities of the surface coefficient of heat transfer. This coefficient is the result of heat transfer by combined natural convection and radiation, whenever a liquid-cooled jacket is not mounted on the external surface of the specimen, see B.2. The temperature non-uniformity on the external surface of the specimen is also due to the uneven thickness and/or air gaps, see also 4.4.9, between the specimen and the apparatus.

NOTE 5: The difference between the pipe surface temperature T_o and the temperature T_2 of the outside surface of the specimen is the appropriate temperature difference when the thermal resistance of a product is being measured. When the thermal conductivity of the material is to be measured, the appropriate temperature difference should be the one between the inside and outside surface of the specimen. If the temperature difference (T_o - T_2) is used instead, additional errors occur due to contact thermal resistances or through mounting techniques of the specimen on the apparatus, see NOTE 1 of 4.4.9.

4.4.8 Error in the measurement of the specimen dimensions

The error of the measuring devices in the measurement of the outside diameter of the specimen shall not exceed 0,5 %, see 8.5 of EN ISO 8497:1994. The deviations from true cylinders of the specimen surfaces are not a source of error of the apparatus, but they shall be carefully considered, especially when the thermal conductivity of the specimen is to be derived. Thermal expansion shall be considered when testing takes place at temperatures significantly away from room temperature.

NOTE: For some non rigid cellular plastics, e.g polyethylene or synthetic rubber, the change in outside diameter for a change of 25 K at the hot side may correspond to a change of 3 % of the specimen thickness.

Further information on measuring techniques for specimen dimensions and related accuracy can be found in prEN 13467:1999.

4.4.9 Error due to an air gap between the specimen and apparatus

Most pipe insulation products are likely to have an air gap between the pipe and insulation product itself to allow for diameter tolerances of both the pipe and the insulation product. The presence of this air gap during the tests corresponds to an added thermal resistance between the specimen and the apparatus. This added thermal resistance is not uniform along the circumference of the pipe when the apparatus is horizontal: the specimen and pipe are in contact on the top of the pipe, i.e. the added thermal resistance is zero, while at the bottom of the pipe the added thermal resistance corresponds to that of an air layer as thick as the difference between the internal diameter of the insulation and that of the outside diameter of the pipe.

There can be two distinctly different objectives in a measurement with the pipe apparatus (see 6.1.1 and 6.1.2 of EN ISO 8497:1994):

- The thermal resistance of the product is to be measured: in this case the air gap is an integral part of the measured property and should not be eliminated.
- The thermal conductivity of the material is to be derived from the measured thermal resistance and specimen dimensions:, in this case the air gap is a significant source of error (see the discussion in 6.2.2 of EN ISO 8497:1994).

To assess the relevance of this last error, the thermal resistance of the air gap may be computed as the ratio between the average air gap thickness and the thermal conductivity of the air, λ_{air}. Values accurate to 0,6 % between θ = 10 °C and θ = 70 °C are given, in W/(m·K), by equation (3)[2)], where $\theta = T_m - 273,15$:

$$\lambda_{air} = 0,0242396\ (1 + 0,003052\ \theta - 1,282 \times 10^{-6}\ \theta^2) \qquad (3)$$

For temperatures exceeding the limits indicated, appropriate text books shall be consulted. As an example, Table 2 gives for some specimen thermal resistances (related to the apparatus surface), the thermal resistance corresponding to 1 % of the specimen thermal resistance and the corresponding average thickness of an air gap at 70 °C (thermal conductivity of the air of 0,0293 W/(m·K)). The effect of other average thicknesses of the air gap is proportional to that of Table 2.

2) Equation (3) has been obtained by regression of the data contained in Encyclopaedia of Gases, Elsevier/Air Liquide, Elsevier Scientific Publishing Company, Amsterdam, 1976.

Table 2 - Average thickness of an air gap at 70 °C corresponding to 1 % of the thermal resistance of the specimen

Specimen thermal resistance $m^2 \cdot K/W$	**Air gap thermal resistance** $m^2 \cdot K/W$	**Equivalent average air gap thickness** mm
0,30	0,0030	0,09
0,40	0,0040	0,12
0,50	0,0050	0,15
0,60	0,0060	0,18
0,80	0,0080	0,23
1,00	0,0100	0,29
1,50	0,0150	0,44

NOTE 1: Table 2 shows that even thin air gaps can represent a significant fraction of the specimen thermal resistance. If necessary, the air gap can be eliminated by filling with a suitable material, or the specimen may be cut axially and pressed against the test pipe.

NOTE 2: The thermal resistance through the air gap due to heat transfer by radiation is 0,11 $m^2 \cdot K/W$ for the temperature of 70 °C, applicable to Table 2. This thermal resistance is always greater than 7 times the thermal resistance due to the conduction through the air gap and hence the effect of radiation heat transfer can be neglected in these testing conditions. For larger air gap thicknesses or high test temperatures, radiation heat transfer may become relevant.

4.5 Equipment performance check

The equipment performance check shall include the following.

- Apparatus dimensions: pipe diameter, the length of the test section and the gap width in guarded-end apparatus shall be measured with an accuracy of 0,5 %, in agreement with similar requirements for specimen dimensions quoted in 8.5 of EN ISO 8497:1994. The surface of the test pipe in contact with the specimen should not deviate from that of an ideal cylinder by more than 0,5 % of the average test pipe diameter.
- Temperature measurements, electrical connections and automatic controllers: check the electrical connections with the following procedure (derived from 2.4.2 of ISO 8302:1994, see [1] in the Bibliography) or one providing equivalent results. A thin low-resistance specimen should be mounted in the apparatus and the whole assembly allowed to reach thermal equilibrium with the laboratory air. During this test, very accurate laboratory conditioning is required. All temperature sensing elements should indicate temperatures which differ from each other by less than 1 % of the lowest expected temperature difference through the specimen and close to the temperature of the air of the laboratory. The same limit applies for noise of each sensor.

  The electrical insulation of all electrical circuits shall also be checked. To do this compute the maximum expected voltage on the heaters of the test pipe; apply a voltage close to the one just computed between the metallic part of the test pipe and one lead of the heater of the test pipe guard or centre (no current should flow); if grounding, guarding and electrical insulation of the temperature sensors are correct, no change will be observed in their readings. Repeat the procedure also at the extremes of the operating temperatures of the equipment (at high temperatures, electrical insulation can exhibit significant deterioration). Check the noise of each automatic control system against the controller specification.

- Temperature measurements: check the temperature sensors with the following procedure (derived from 2.4.3 of ISO 8302:1991, see [1] in the Bibliography) or one providing equivalent results. If the equipment is equipped with a temperature-controlled jacket, mount a specimen and regulate the jacket temperature at some relevant values within its range.

  Do not supply any electrical power to the heaters of the test pipe centre or guard. The test pipe centre temperatures shall match the jacket temperature within the noise of the measuring system. The test pipe guard temperature shall be balanced to the temperature of test pipe centre within the noise of the imbalance-detection instrumentation. Wrong results can be due to poor design of the jacket (in particular at the ends of the test pipe) or to wrong wiring and connections of temperature sensors.

- Imbalance errors: equation (1), applied to measurements with several different imbalance temperature differences ΔT_g on specimens of at least two thermal conductivities (close to the minimum and maximum expected thermal conductivities for the equipment), allows the determination of c and Φ_o by a least-squares analysis. During these experiments, all testing conditions shall be kept unchanged, except the temperature of the test pipe guard, which is modified to obtain the desired temperature differences ΔT_g. The values of Φ_g are the differences between the values of Φ at a given imbalance ΔT_g and that of Φ in balance conditions.

  NOTE This procedure is equivalent to that described in 2.4.4 of ISO 8302:1991, see [1] in the Bibliography.

- End heat losses: this source of error shall be assessed theoretically, see 4.4.2 and B.1, because there is no proven standard experimental procedure to assess it. Some indications on end heat losses may be derived if reference materials or homogeneous materials already tested in a guarded hot plate are available to prepare test specimens of increasing thickness.

- Emissivity of apparatus surfaces: for measurements at high temperatures or on low density materials, where the thickness effect can be relevant, the emissivity of apparatus surfaces in contact with the specimen can be determined with procedures equivalent to those described in Annex A of Part 2 of this standard, by using metal pipes having diameters a few millimetres greater than the external diameter of the test pipe and by replacing equations A.1 and A.2 of Part 2 of this standard, applicable to plane surface, with the following ones, appropriate for coaxial cylinders.

The total density of heat flow rate, q_t, may be written as:

$$q_t = q_r + \frac{\lambda_{air}}{0{,}5 d_o \ln(d_2 / d_o)} \Delta T \qquad (4)$$

where:

λ_{air}	is the thermal conductivity of the air, see equation (3);
d_o	is the external diameter of the test pipe, in m;
d_2	is the internal diameter of the metal pipe coaxial with the test pipe, in m;
ΔT	is the temperature difference between the two surfaces, in K;

and q_r is:

$$q_r = \frac{4\sigma_n T_m^3 \Delta T}{1/\varepsilon_o + (d_o / d_2)(1-\varepsilon_2)/\varepsilon_2} \qquad (5)$$

where:

T_m is the mean temperature of the two surfaces, in K;

σ_n is the Stefan Boltzmann constant ($5{,}67 \times 10^{-8}$ W/($m^2 \cdot K^4$));

ε_o, ε_2 are the emissivities of the surfaces of the pipes.

For materials not subject to thickness effect, the apparatus emissivity need not be measured close to room temperature, provided the apparatus surfaces are painted with non-metallic paint (because the limit of 0,8 stated in 7.11 of EN ISO 8497:1994 is so met).

- Linearity test (derived from 2.4.7 of ISO 8302:1991, see [1] in the Bibliography): if a suitable thermally stable material is available, having a thermal conductivity which is a linear function of the mean test temperature, mount a specimen of such a material and measure the thermal conductivity at a given mean test temperature with widely different temperature differences. The smallest temperature difference shall be such as to correspond to the minimum density of heat flow rate expected during all possible testing conditions. The results shall be independent of the temperature difference. Repeat the procedure at some other relevant mean test temperatures. Mean test temperatures shall span the whole temperature range of the equipment. If the linearity test results deviate even by a small fraction of a percentage point from the expected density of heat flow rate in the range of densities of heat flow rate expected during the measurements, a bad placement of imbalance sensors is the most probable reason. The imbalance error detected by the linearity test depends on the particular testing conditions employed and cannot be estimated for other testing conditions. If the deviations of the results of the linearity test exceed those acceptable for imbalance errors, the equipment shall not be approved.

The results of the performance checks shall be incorporated in the equipment manual. They shall comply with the requirements stated in EN ISO 8497:1994 and should confirm the calculations described in 4.4 of this standard within the accuracy of the assumptions for such calculations.

5 Calibration and maintenance files

Calibration and maintenance files shall be kept containing records of maintenance, repair or modification to the equipment and all periodic calibration data, as indicated in this clause and of calibrations indicated in 5.3 of Part 1 of this standard.

NOTE: Temperature sensors include thermocouples, thermopiles and resistance thermometers.

These calibration and maintenance files shall contain records of the calibrations and periodic verifications of the end caps, see 7.4 of EN ISO 8497:1994.

The ancillary equipment requiring periodic calibration checks include: digital voltmeters, power supplies, voltage and current transducers, standard resistances, thickness transducers, etc..

Appropriate periodic maintenance may be required for some ancillary devices. When applicable, the nature of any such maintenance shall be described, together with its schedule and the annotation to be made on the calibration and maintenance files.

As the pipe test method is an absolute method, its results shall never be corrected using the results of measurements on reference materials. Rather, the equipment design and all the associated instrumentation shall be checked until the cause of disagreement has been identified and rectified. Nevertheless it is recommended that a verification with one or more reference materials be performed not only after the initial performance check but also at regular intervals e.g. once a year.

6 Measurement procedure document

A measurement procedure document shall be compiled in accordance with 5.4 of Part 1 of this standard. Specific information on specimen handling and conditioning, measurement procedures and data reporting are described in clauses 8 to 13 of EN ISO 8497:1994.

The measurement procedure document shall include, for a given pipe test apparatus, the criteria for the assessment of the attainment of steady-state conditions and for the definition of the measurement interval.

Measurement procedures described in a material specification for a specific material shall override the general requirements indicated in EN ISO 8497:1994.

7 Assessment

The assessment shall be implemented in accordance with clause 4 of Part 1 of this standard.

Particular care shall be taken during the assessment in the verification of the design, error analysis and performance check data contained in the equipment manual.

> NOTE: This is essential to ensure that the prescribed accuracies are met in all testing conditions for which the approval is sought. Supplementary calculations or experimental performance checks may be required before the on-site assessment.

If the design is not adequate to reach the specified accuracy level in the intended test conditions, the laboratory shall either revise the equipment design and construction or reduce the range of testing conditions. If it is impossible to find a suitable range of testing conditions in which the equipment reaches the needed level of accuracy, then, clearly, the equipment fails to meet the requirements for approval.

It would be advisable to ask for one or more of the performance checks indicated in 4.5 to be repeated.

The approval shall not be granted without proficiency tests.

Annex A (normative)

Limits for equipment performance and test conditions - Pipe test methods

A.1 Accuracy and repeatability, stability, uniformity

Clause in EN ISO 8497:1994	Description	Value
7.9	required accuracy of measuring system to measure the average power of the test section	± 0,5 %
7.10	maximum temperature fluctuation of the ambient air allowed for a temperature difference between the test pipe and the ambient air of no more than 200 K	± 1 K
7.10	maximum temperature fluctuation of the ambient air allowed for a temperature difference between the test pipe and the ambient air of more than 200 K	± 2 K
8.5	required accuracy in the measurement of the outside dimensions of the specimen	± 0,5 %
9.2	maximum fluctuations allowed for ambient temperature	± 1 K
9.2	required stability of ambient temperature related to the temperature difference between the test pipe and the ambient	± 1 %
9.4	maximum error in the measurement of the heat flow rate caused by the temperature difference across the gap	1 %
9.4	maximum allowed imbalance related to the temperature drop through the specimen	0,5 %
9.5.2.2	maximum specimen axial heat flow rate allowed as percentage of the average heat input to the test section	1 %
9.5.3	minimum duration of the period of observation in which the required data are determined, after steady-state conditions have been attained	0,5 h
9.5.3	maximum allowed difference of average power and average temperature difference measured in the fourth period of observation from the average values measured in the other three periods of observation	1 %
10.1.3	maximum allowed difference of average power and average temperature difference measured in the fourth period of observation from the average values measured in the other three periods of observation	1 %
10.2.2.2	minimum distance from the middle of the apparatus to the thermocouples installed according to the method of van Rinsum	200 mm

A.2 Equipment design requirements

Clause in EN ISO 8497:1994	Description	Value
7.3	maximum width of the gap between the guards and test section of the apparatus	4 mm
7.3	maximum distance between the gap and the junction of balancing thermocouples installed on the test pipe	25 mm
7.4.1	minimum number of thermocouples on the surface of the calibrator pipe	4
7.4.1	maximum thermocouple diameter when mounted in the surface of the calibrator pipe to measure its temperature	0,64 mm
7.5	recommended minimum number of thermocouples in the pipe metering section to measure its surface temperature	4
7.5	distance between the thermocouples in the pipe metering section to measure its surface temperature	150 mm
7.6	maximum thermocouple diameter when measuring metallic surfaces	0,63 mm
7.6	maximum thermocouple diameter when measuring non-metallic surfaces	0,4 mm
7.10	minimum hemispherical emissivity of the surfaces seen from the apparatus	0,85
7.11	minimum hemispherical emissivity of the internal surfaces of the jacket or added insulation	0,80
8.6.2.1	minimum length of adjacent wire of thermocouples that shall be held in contact with non-metallic surfaces	100 mm
8.6.2.1	recommended size for sheets of metal foil to use to fasten the thermocouples when the specimen surface is non-uniform in temperature	20 mm x 20 mm
8.6.2.2	minimum length of adjacent wire of thermocouples that shall be held in contact with metallic surfaces	10 mm
8.7	recommended distance for thermocouples from each side of the gap	45 mm
9.1	recommended range of the temperature during most of dimension measurements	from 10 °C to 35 °C

A.3 Acceptable specimen characteristics

Clause in EN ISO 8497:1994	Description	Value
8.5	maximum departure of the outside specimen dimension throughout its length from the average of the test section measurements	5 %

A.4 Acceptable testing conditions

Clause in EN ISO 8497:1994	Description	Value
8.4	recommended range of temperatures to dry specimens, unless the specimen would be adversely affected	102 °C to 120 °C
9.5.3; 10.1.3	minimum required length of the measurement period	0,5 h

Annex B (informative)

Axial heat flow rate and temperature uniformity

B.1 Axial heat flow rate and maximum specimen thickness

The error $E_e = \Phi_e/\Phi$ due to the axial heat flow rate Φ_e in the guarded-end apparatus may be computed by the following equation:

$$E_e = \left\{ \frac{d_{eq}}{\pi l} \left[e \ln \frac{\cosh\left(\pi (b + l)/d_{eq}\right) + 1}{\cosh\left(\pi b/d_{eq}\right) + 1} + (1 - e) \ln \frac{\cosh\left(\pi (b + l)/d_{eq}\right) - 1}{\cosh\left(\pi b/d_{eq}\right) - 1} \right] \right\} - 1$$

where:

- b is the length of each guard at the end of the test pipe;
- l is one half of the test section length L;
- e is the end temperature ratio defined in 4.4.2.2;
- d_{eq} is an equivalent specimen thickness defined as: $d_{eq} = 0{,}5\ d_2 \ln(d_2/d_o)$

and:

- d_o is the outer diameter of the test pipe;
- $d_2 = 2$ (specimen thickness) $+ d_o$ is the outer diameter of the specimen.

NOTE: The above equation is the two-dimensional equivalent of the one quoted in 2.2.1 of ISO 8302:1991, see [1] in the Bibliography (the expression in braces is not squared here). The introduction of the equivalent specimen thickness d_{eq} equates the error due to axial heat flow rate to that in a two-dimensional layer crossed by the same density of heat flow rate at the outer surface of the specimen. This assumption is likely to give a conservative estimate of the error E_e.

Table B.1 shows for some apparatus dimensions and specimen thicknesses the error due to axial heat flow rate according to the equation (B.1) when there is no end insulation and when the end temperature ratio e, see 4.4.2.2, is taken to be 0. The latter assumption allows for the apparatus being placed in surroundings whose temperature is lower than that of any part of the apparatus or specimen. Error values are in bold characters when greater than 1 %, see 4.4.2.1, while are not given if greater than 10 %.

Larger specimen thicknesses can be used if end insulation, auxiliary guards or gradient guards are used.

When an additional outer guard is used, calculate the error due to axial heat flow rate using a guard width equal to the sum of the width of the principal and additional guards.

Table B.1 - Errors due to end heat losses in case of no end insulation and end temperature ratio e = 0

Dimensions in millimetres

Overall size	**Pipe centre**	**Guard width**	**Pipe diameter**	**Error, expressed in %, for different specimen thicknesses**				
				25	40	60	100	150
				d_{eq} 30,4	52,9	86,7	165	277
1 000	400	300	100	0,00 %	0,00 %	0,00 %	0,17 %	**2,69 %**
1 000	700	150	100	0,00 %	0,00 %	0,07 %	**1,77 %**	**10,00 %**
1 000	800	100	100	0,00 %	0,02 %	0,37 %	**4,22 %**	--
				d_{eq} 34,7	62,1	104	201	340
1 000	400	300	50	0,00 %	0,00 %	0,00 %	0,57 %	**5,95 %**
1 000	700	150	50	0,00 %	0,01 %	0,21 %	**3,68 %**	--
1 000	800	100	50	0,00 %	0,06 %	0,83 %	**7,53 %**	--
				d_{eq} 41,2	75,3	127	247	417
1 000	400	300	25	0,00 %	0,00 %	0,03 %	**1,62 %**	--
1 000	700	150	25	0,00 %	0,03 %	0,58 %	**7,16 %**	--
1 000	800	100	25	0,00 %	0,19 %	**1,80 %**	--	--
				d_{eq} 50,3	92,6	156	301	503
1 000	400	300	12,5	0,00 %	0,00 %	0,12 %	**3,76 %**	--
1 000	700	150	12,5	0,00 %	0,10 %	**1,43 %**	--	--
1 000	800	100	12,5	0,02 %	0,50 %	**3,59 %**	--	--
				d_{eq} 62,5	114	192	364	602
1 000	400	300	6	0,00 %	0,01 %	0,43 %	**7,50 %**	--
1 000	700	150	6	0,01 %	0,34 %	**3,12 %**	--	--
1 000	800	100	6	0,07 %	**1,21 %**	**6,59 %**	--	--

When the apparatus is operated with a jacket maintained at a temperature higher than the ambient temperature and no insulation is used at the ends of the apparatus, the end temperature ratio may be less than 0 (negative), hence the error due to axial heat flow rate may be greater than that indicated in Table B.1.

EXAMPLE: A mean test temperature of 85 °C, a temperature difference through the specimen of 100 K and a laboratory temperature of 25 °C give e = -0,1.

Table B.1 is based on purely conductive models. For low density materials (e.g. less than 20 kg/m^3) or specimens tested at high temperatures, where a considerable amount of radiation heat transfer takes place, the error E_e is larger and it is in any case advisable not to exceed the conservative thicknesses allowed from the data of Table B.1, unless the calculations of end heat loss errors include coupled conduction and radiation heat transfer.

The information given in this clause is based on an assumption of isotropic specimens, and it is not suitable for assessing the performance of equipment intended for testing non-isotropic or layered specimens.

B.2 Evaluation of the temperature non-uniformity on the external surface of the specimen

When attempting the evaluation of the temperature non-uniformity on the external surface of the specimen, the surface coefficient of heat transfer by radiation, h_r, can be approximated by $h_r = 4\ \varepsilon\ \sigma_n\ T_m^3$, where σ_n is the Stefan- Boltzmann constant, ε is the total hemispherical emissivity of the surface of the specimen and T_m is the arithmetic mean of the temperature T_2 of the surface of the specimen (measured according to 7.6 and 8.6 of EN ISO 8497:1994) and the mean radiant temperature of the surfaces "seen" by the external surface of the specimen. The non-uniformity of these temperatures is one of the sources of the temperature non uniformity of the surface of the specimen.

The second source of temperature non-uniformity is the fact that the surface coefficient of heat transfer due to natural convection, h_c, is not uniform along the circumference of the specimen. To evaluate local values of h_c, use the following expression: $Nu = 0{,}604\ Gr^{1/4}\ \ \Phi(\alpha)$, where $Nu = h_c\ d_2/\lambda_{air}$ is the Nusselt number, with λ_{air} thermal conductivity of the air, see 4.4.9, and $Gr = d_2^3 g\ (T_2 - T_a)/\ \nu^2\ (T_2 + T_a)/2$ is the Grashof number, with g gravity acceleration, T_a air temperature, ν cinematic viscosity; $(T_2 + T_a)/2$ shall be in K. The function $\Phi(\alpha)$ gives the variation of the surface coefficient of heat transfer with the angular position, α, measured from the horizontal position, and is given below:

α	-90 °	-60 °	-30 °	0 °	30 °	60 °	75 °	90 °
$\Phi(\alpha)$	0,76	0,75	0,72	0,66	0,58	0,46	0,36	0
	——— bottom half ———				——— top half ———			

The above expression and numerical data were confirmed experimentally for Gr in the range 25 000 to 50 000.

Annex C (informative)

Calculations of some pipe test apparatus errors

C.1 General

Error analyses are supplied here for common sizes of equipment. If the equipment to be considered corresponds to the design indicated in this annex, no further calculations need be made. Otherwise, analogous calculations can be done for the specific equipment. The main apparatus characteristics and testing conditions, for three pieces of equipment, are assumed and collected in Table C.1. Equipment A and B are guarded-end type apparatus, equipment C is a calculated-end one.

Table C.1 - Main pipe test apparatus characteristics and test conditions

	EQUIPMENT		
	A	**B**	**C**
- overall pipe length in mm	1 000	1 000	1 000
- pipe test section length in mm (centre gap to centre gap)	600	400	---
- pipe guard length in mm (centre gap to guard external end)	200	300	---
pipe diameter in mm	100	25	50
- maximum gap width in mm	6	4	---
- minimum specimen conductivity in W/(m·K)	0,015	0,015	0,015
- maximum specimen conductivity in W/(m·K)	0,2	0,2	0,2
- maximum specimen thickness in mm (see C.2 and 4.4.2)	95	85	85
- maximum thickness of the pipe in mm (assumed copper, 400 W/(m·K))	5	2	3
- maximum total section in mm^2 of copper wires (400 W/(m·K)) crossing both gaps	6	6	---
- maximum total section in mm^2 of non-copper wires (100 W/(m·K)) crossing both gaps	6	6	---
- maximum total section in mm^2 of mechanical connections (0,3 W/(m·K)) through both gaps (eight blocks of the dimensions indicated in mm in brackets for each equipment)	3240 (15 × 27)	832 (8 ×13)	--- ---

C.2 Maximum specimen thickness

	A	B	C
Maximum specimen thickness in mm for the apparatus sizes of Table B.1 (or their interpolation), to keep the end heat loss error within 1 %, according to 4.4.2.	100[3)]	90[3)]	85[4)]

3) see Annex B and Table B.1

4) see 4.4.2.3 in this standard and Figure 3 in EN ISO 8497:1994 (Nukiyama correction) for n = 0,6 and S = 25 mm

	EQUIPMENT A	B	C

C.3 Imbalance error

	A	B	C
The value of c in m, according to 4.4.4, is:	0,630	0,171	---

This corresponds to the products λc in W/K:

	A	B	C
- for the minimum specimen thermal conductivity $\lambda = 0{,}015$ W/(m·K), see Table C.1	0,00944	0,00257	---
- for the maximum specimen thermal conductivity $\lambda = 0{,}2$ W/(m·K), see Table C.1	0,126	0,0342	---

The term Φ_o is the sum of:

- Φ_a through the air in the gap (heat flow rate between two circular surfaces of diameter d_o and distance g; at 70 °C $\lambda_{air} = 0{,}0293$ W/(m·K));
- Φ_r by radiation through the gap (heat flow rate between two circular surfaces of diameter d_o and total hemispherical emissivity $\varepsilon = 0{,}9$; mean temperature of 70 °C);
- Φ_m through the mechanical connections across the gap (total section and thermal conductivity as in Table C.1);
- Φ_c through copper wires (total section and thermal conductivity as in Table C.1);
- Φ_w through metal wires (excluding copper; total section and thermal conductivity as in Table C.1))

	A	B	C
The term Φ_a in W/K is:	0,0767	0,00719	---
The term Φ_r in W/K is:	0,118	0,00736	---
The term Φ_m in W/K is:	0,162	0,0624	---
The term Φ_c in W/K is:	0,400	0,600	---
The term Φ_w in W/K is:	0,100	0,150	---
The term Φ_o in W/K is:	0,856	0,827	---

by adding λc, the sum ($\Phi_o + \lambda c$) in W/K is:

	A	B	C
- for the specimen conductivity 0,015 W/(m·K)	0,865	0,830	---
- for the specimen conductivity 0,2 W/(m·K)	0,982	0,861	---

Assuming a temperature difference through the specimen of 40 K for the specimen conductivity 0,015 W/(m·K) and a temperature difference through the specimen of 20 K for the specimen conductivity of 0,2 W/(m·K), the corresponding lineal densities of heat flow rates Φ/L at the maximum specimen thickness, see equation (5) of EN ISO 8497:1994 for $L = 1$ m, are in W/m:

	EQUIPMENT A	EQUIPMENT B	C
- for the specimen conductivity 0,015 W/(m·K)	3,43	1,79	---
- for the specimen conductivity 0,2 W/(m·K)	22,88	11,94	---

and the heat flow rates in W through the pipe centre section of length *L* are:

	A	B	C
- for the specimen conductivity 0,015 W/(m·K)	2,06	0,72	---
- for the specimen conductivity 0,2 W/(m·K)	13,73	4,78	---

To ensure an error less than 1 %, see 4.4.4, the value of ΔT_g in mK shall be smaller than:

	A	B	C
- for the specimen conductivity 0,015 W/(m·K)	23,8	8,64	---
- for the specimen conductivity 0,2 W/(m·K)	139,8	55,5	---

Assuming a balancing thermopile of 8 elements with a thermoelectric power of 45 μV/K per element, the electrical balance in μV shall be better than:

	A	B	C
- for the specimen conductivity 0,015 W/(m·K)	8,6	3,1	---
- for the specimen conductivity 0,2 W/(m·K)	50,3	20,0	---

The maximum acceptable value for ΔT_g is compared with the accuracy of the balancing thermopile in detecting the temperature imbalance through the gap. The calculations may be as follows.

The above calculated lineal densities of heat flow rates Φ/L at the maximum specimen thickness (in W/m), correspond to the following densities of heat flow rate (in W/m²) at the pipe surface in contact with the specimen:

	EQUIPMENT A	EQUIPMENT B	C
- for the specimen conductivity 0,015 W/(m·K)	10,9	22,8	---
- for the specimen conductivity 0,2 W/(m·K)	72,8	152,1	---

Considering the above calculated densities of heat flow rates crossing the metal pipe (copper, 400 W/(m·K)), the temperature differences, in mK, across the pipe, according to equation 5 of EN ISO 8497:1994, are:

	A	B	C
- for the specimen conductivity 0,015 W/(m·K)	0,14	0,12	---
- for the specimen conductivity 0,2 W/(m·K)	0,96	0,83	---

These values are less than the maximum acceptable values for ΔT_g and hence any position along the thickness of the heating metal pipe is satisfactory. Consequently, the gap design of Figure D.3 a) of EN 12667 (thermopile junctions placed in holes within the metal pipe), under the above assumptions, does not require further checks, while all other solutions require the analysis of the uniformity of the thermal resistance between the metal pipe and the thermopile junction.

For thermopiles embedded in plastic sheets (e.g. as in Figure 4 a) of ISO 8302:1991, see [1] in the Bibliography), the effect of an air pocket 0,01 mm thick (air conductivity of 0,029 W/(m·K)) or the effect of a 0,1 mm difference in thickness of the plastic layer (plastic conductivity of 0,29 W/(m·K) between the junctions on each side of the gap and the metal pipe corresponds to a thermal resistance of 0,000345 m^2·K/W. When the above calculated densities of heat flow rates cross the thermal resistance of 0,000345 m^2·K/W, the resulting temperature differences in mK, across it are the following.

	EQUIPMENT		
	A	B	C
- for the specimen conductivity 0,015 W/(m·K)	3,77	7,87	---
- for the specimen conductivity 0,2 W/(m·K)	25,1	52,4	---

It appears then that a gap design as in Figure 4 a) of ISO 8302:1991, see [1] in the Bibliography, i.e. the thermopile mounted within plastic sheets, is critical for the equipment B, even though particular care has been taken to avoid air pockets and local non-uniformities in the mounting of thermopile junctions.

C.4 Error in measured electrical power

7.9 of EN ISO 8497:1994 limits this error to 0,5 %.

C.5 Error in the definition of the metering area

The metering area is defined as the area enclosed by the lines through the centre of the gaps. An uncertainty equal to the gap width (1 %) can be accepted plus 0,1 % due to mechanical tolerances, i.e.:

EQUIPMENT		
A	B	C
1,1 %	1,1 %	---

The 1 % uncertainty is reduced to 0,2 % if the specimen thickness is at least 10 times larger than the gap width, g.

C.6 Error in the temperature difference

Differential connections are assumed for special grade type T thermocouples operated around room temperature. According to 4.4.7 a 0,4 % uncertainty in the calibration can be assumed.

The accuracy may be assumed to be 0,2 %.

The temperature uniformity is assumed within 0,5 K and 0,7 K for the pipe and external surface of the specimen respectively. The resulting errors are assumed one half of the above, and these, added in quadrature, give an error of 0,43 K. This is 1,1 % for a 40 K temperature difference and 2,2 % for a 20 K temperature difference.

The sum of the above errors is 1,7 % for a 40 K temperature difference and 2,8 % for a 20 K temperature difference.

C.7 Error in the measurement of outside dimensions of the specimen

According to 8.5 of EN ISO 8497:1994, the error in the measurement of the outside dimensions of the specimen is limited to 0,5 %, which, applied to a thin specimen whose outside diameter approaches the pipe diameter, gives the following absolute errors in mm:

EQUIPMENT		
A	**B**	**C**
0,50	0,13	0,25

C.8 Error due to imperfect contact between apparatus and specimen

Contact resistances between the specimen and apparatus due to the presence of an air gap become critical at low specimen thermal resistances whenever the specimen thermal conductivity is being determined or when it is necessary to extrapolate the measurement on a specimen of given dimensions to specimens of different dimensions.

Considering a specimen having the maximum thermal conductivity to be measured (0,2 W/(m·K)), even at the maximum specimen thicknesses (100 mm, 90 mm and 85 mm for equipment A, B and C respectively), the corresponding thermal resistances related to the pipe surface, in $m^2 \cdot K/W$, are:

EQUIPMENT		
A	**B**	**C**
0,275	0,132	0,185

An air gap 1 mm thick at 70 °C has a thermal resistance of 0,0342 $m^2 \cdot K/W$. If specimens with the above thermal resistances are tested, the error due to the presence of an air gap 1 mm thick introduces the following percent errors:

EQUIPMENT		
A	**B**	**C**
12,4 %	26,0 %	18,4 %

If this calculation is repeated for a specimen having the thermal conductivity of 0,015 W/(m·K), the resulting errors become:

EQUIPMENT		
A	**B**	**C**
0,93 %	1,95 %	1,38 %

This error can therefore be the most important one for low resistance specimens when the thermal conductivity of the material is of interest.

C.9 Maximum probable error

The maximum probable error in percent is obtained from the individual components calculated in C.2 to C.8

	EQUIPMENT A	EQUIPMENT B	C
Imbalance error	1,0 %	1,0 %	--- %
End heat loss error	1,0 %	1,0 %	--- %
Error in measured electrical power	0,5 %	0,5 %	0,5 %
Error in the definition of the metering area	1,1 %	1,1 %	--- %
Error in the temperature difference of 20 K	2,8 %	2,8 %	2,8 %
Error in the outside dimension	0,5 %	0,5 %	0,5 %
By summing, the maximum error is:	6,9 %	6,9 %	3,8 %
If the above errors are added in quadrature, the maximum probable error is:	3,4 %	3,4 %	2,9 %

Random errors due to random drifts of measurement instrumentation and automatic control systems, which can be minimized by averaging many measurements, have not been included in this error analysis.

The above errors apply when the thermal resistance due to the presence of an air gap is included in the thermal resistance of the pipe insulation to be tested. If the thermal conductivity is of interest, the error due to imperfect contact shall be added. In C.8 the following errors were computed for a specified set of testing conditions:

	EQUIPMENT A	EQUIPMENT B	C
- for the specimen conductivity 0,2 W/(m·K)	12,4 %	26,0 %	18,4 %
- for the specimen conductivity 0,015 W/(m·K)	0,93 %	1,95 %	1,38 %

If this error is added in quadrature with the above listed ones, the maximum probable errors are:

	EQUIPMENT A	EQUIPMENT B	C
- for the specimen conductivity 0,2 W/(m·K)	12,9 %	26,2 %	18,7 %
- for the specimen conductivity 0,015 W/(m·K)	3,5 %	3,9 %	3,2 %

Bibliography

[1] ISO 8302:1991, *Thermal insulation - Determination of steady-state thermal resistance and related properties - Guarded hot plate apparatus*

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